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MASKING OF PURE TONES AND SPEECH

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Abstract

One of the basic shortcomings of the Articulation Index (AI) as originally formulated was the inability of that method to predict the effects of the spread of masking from a band of noise to frequency regions above and below that occupied by the band of noise itself. Inasmuch as the masking of speech by noise is often a major problem in military communications, it was necessary to modify the calculation procedures for AI if the AI method is to be useful to communications engineers concerned with military problems. The studies herein reported investigated the masking effects of intense pure tones and bands of noise upon other pure tones and speech. Of perhaps special importance are the masking effects of very intense low frequency sounds, in that low frequency sounds are present near missile launch sites. On the basis of the test results, spread of masking functions were obtained that can be incorporated into procedures for the calculation of a "new" Articulation Index that will be valid for a much wider variety of noise conditions than heretofore possible.

Reviewed and approved for publication

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SUMMARY

The report summarizes the main empirical findings in the literature concerned with the masking of pure tones and speech by pure tones and narrow bands of noise.

Three new experiments are described. Experiment I, primarily done to determine the masking pattern upon pure tones over the audible range of tones of 50 to 100 cps, also used masking tones of 200 cps, 400 cps, 1000, 2000, 3000, 4000 and 8000 cps. The results showed general agreement at the higher frequencies with other studies using similar techniques and comparable frequencies and levels of the masking tone; comparable data for the very low frequencies have not, to our knowledge, been presented before.

A second experiment was done to get data on the effect of high level, low frequency pure tones on the perception of PB word lists.

The third experiment examined the extent to which irregularities peaks and troughs in the masking curves, were due to combination tones formed by the masking and signal tones. Six 100 cps bands were used ranging in center frequency from 200 cps to 4000 cps. The results confirmed that irregularities in the curves are reduced and that the upward spread of masking is also reduced when a narrow band noise rather than a pure tone is used as the masker.

MASKING OF PURE TONES AND SPEECH

N. L. Carter
K. D. Kryter

INTRODUCTION

Licklider[1] has defined masking as ". . .the inability of the auditory mechanisms to separate the tonal stimulation into components and to discriminate between the presence and absence of one of them." Tanner[2] has pointed to experiments in which decrement of performance by "distraction" and distortion occur, and questions whether the definition of masking should be modified to include them. He also considers that masking by white noise "appears to be both physical and psychological." For our purposes masking refers to the limits placed on the recognition of a sound by the presence of another sound, when the time and frequency characteristics of both are known to the observer, and when he is oriented to perceive them. The definition includes intra-aural distortion products as one of the consequences of both stimuli.

The study of masking has been of considerable theoretical value in deriving models of the frequency resolving characteristics of the ear and in some cases of generating hypotheses of cochlear activity which have subsequently been confirmed.[3,4,5] In addition, the effects of masking are of considerable practical importance, particularly with respect to speech communications. Indeed, our major concern in this paper is with the application of the functions for the spread of masking found with pure tones to the problem of speech communications in the presence of interfering tone or noise.

Considerable research has been conducted in this area in the past and before presenting our own experimental results, we review briefly the findings concerned with (1) the masking of pure tones by pure tones, (2) the masking of speech by pure tones, (3) the masking of pure tones by narrow bands of noise, and (4) the masking of speech by narrow bands of noise.

REVIEW OF THE LITERATURE

1. Masking of Pure Tones by Pure Tones

Probably the first experimental observation of the masking of pure tones by pure tones was reported by A. A. Mayer in 1876. The study by Wegel and Lane[6] of the Bell Telephone Laboratories in 1924 was, however, the first to use electronic means of producing and controlling the stimuli, systematically vary the physical parameters of amplitude and frequency and to use adequate replication of subjects and observations. Air-damped telephone receivers, vacuum tube oscillators, and filters were used to ensure the "purity" of the tones. Masking frequencies ("primary tones" or fp) and signal (secondary, fs) tones were used at four sensation levels for fp = 200 and 300 cps, and five sensation levels for the remainder. The range of test frequencies (fs) was from 150 to 4000 cps.

The main findings of the study have been summarized by Licklider[1] and Fletcher.[7] They are: (1) the degree of threshold shift of fs is a linear function of the sensation level of fp only at frequencies of fs close to fp, i.e. within 50 cps for the range of fps studied; (2) departures from linearity are much more marked for frequencies of fs higher than fp than lower. Masking curves for these frequencies become increasingly positively accelerated and cross those of tones below the masking frequency at high levels of fp; (3) as a corollary of the above, masking by low frequencies of high is greater than the reverse; (4) sharp dips are apparent at f's which are integral multiples of the masking tones, at sensation levels equal to or higher than 60 db. They become more pronounced with increasing level and frequency of the masking tone and are produced by fs beating with fp or by harmonics of it generated in the ear as a consequence of its nonlinearity. Broader "troughs" are apparent also in the curves plotting threshold shift by fs at high levels of fp.

Questions raised by the study concern (a) the criterion of detection of the signal tone, (b) the degree of variability to be expected between subjects and within subjects at different times (c) the effect of "smoothing" the curves between the seven or eight test frequencies, (d) the effect at test frequencies below 150 and above 4000 cps, (e) the masking produced by frequencies below 200 cps, and (f) the invariance of the data with differences in the method of presenting the signal tones. Data on (a) and (f) were obtained by Ehmer,[8/] and (b) and (f) by Small[9/] in 1958.

Ehmer studied the masking pattern of pure tone frequencies 250, 500, 1000, 2000, 4000 and 8000 cps, at five sensation levels (SL) from 20 to 100 db, except at 250 cps, where the range was 20-80 db. A Bekesy audiometer was used, and the threshold shift determined at 15 points per octave from 100 to 8000 cps.

The main findings of the study were as follows:

(1) Masking curves are symmetrical at 20 db SL for all frequencies of the masking tone except 250 cps, showing "extended" masking on the high frequency side. Wegel and Lane's data also show clear asymmetry at 200 cps, 20 db SL, less apparent at higher frequencies of fp.

(2) Extension of masking to the higher frequencies is more marked for lower frequencies of the masking tone and nonlinearly related to level of fp, also confirming earlier findings.

(3) Curves for the lower frequencies are relatively "smooth." Those for higher frequencies and levels in excess of 60 SL show progressively more marked changes in the degree of masking of higher frequencies of fs.

(4) There are no sharp "dips" at harmonics of fp as is characteristic of the data by Wegel and Lane. Instead, (a) troughs appear at one-half octave above fp at SL's greater than 60, and (b) a second peak occurs immediately above this. Both the trough and the second peak "migrate" upwards in frequency as level of fp is raised, the second peak approximating the second harmonic of fp at 100 db SL. An exception to this is at fp = 4 KC, where the second peak occurs at 6 KC.

(5) For frequencies 500 cps, 1 KC, 2 KC, and 4 KC a third peak is discernible in the data. This approximates the third harmonic for 500 cps and 1 KC fp, and the second harmonic for 2 KC and 4 KC.

The main differences in the findings of this study and that by Wegel and Lane at comparable frequency and sensation levels of fp are (1) the presence of second and third migrating peaks and (2) the absence of clearly defined harmonic "dips" in Ehmer's data.

Small[9/] used variable masking tones with fixed signal tones. Data are given for signal tones of 400, 600, 800, 3200 and 6400 at two SL's, 15 and 30 db. Masking tones were adjusted by S to the level necessary to mask the signal tones, their (the fp's) frequency being common multiples of fs; i.e., for each fs, fp = 0.05, 0.1, 0.2, 0.35, 0.5, 0.7, 0.8, 0.9, 0.95, 1.05, 1.2 and 3.0 fs. Data are thus available on the masking effect of three tones (20, 40 and 80 cps) below 100 cps, on the five signal frequencies.

Findings common to other studies include (1) asymmetrical masking for low and high frequencies of the masker. This is illustrated by the sharp slope of Lm (level of masking tone) when fm > fs, (2) minimum level of fm necessary to mask fs occurs when fm is close to (slightly above) fs.

There are, however, some differences. (1) The slope of the curve relating the increase in masking to level of the masking tone is (a) > +1 for frequencies of the masking tone close to those of the signal, and (b) varies with fs. (2) A second "notch" or point of minimum masking (maximum Lm) is apparent for Ls = 30 at fm/fs of 0.85. There is no obvious relationship with harmonics of the fundamental at this point. (3) For equal relative frequencies (fm/fs) of the masking and signal tones the level of the masking frequency necessary appears greater for fs 400 and 6400 than for intermediate frequencies. This is less evident at Ls 30 than Ls 15. (4) In general, the degree of masking by a given fm is less by 2-10 db than that shown by Wegel and Lane, but roughly equal to Egan and Hake's[10/] results, at comparable frequencies.

2. Masking of Speech by Pure Tones

A study of the masking of speech by pure tones was reported by Stevens, Miller and Truscott in 1946.[11/] The speech material was connected discourse presented binaurally through a pair of PDR-10 earphones connected in series. Nine masking tones ranging from 100 to 2000 cps were mixed with the speech at 112, 102, 92, 82, 72, and 62 db SPL. The dependent variable was the detectability threshold shift in db.

The results are summarized in Fig. 1 from the published paper.[11/] As the authors note the most effective masking frequency shifts from at least 500 cps at the lower levels of the masking stimulus to 300 cps at higher levels. The degree of maximum shift is roughly linear with SPL (fp) greater than 72 db, and reaches 56 db for a 300 cps tone of 112 db SPL. Frequencies above 200 cps produce very little threshold shift.

It is of interest that the growth functions of detectability threshold shift vary in shape with change in the pure tone frequency. A plot of these functions, drawn from Fig. 1, is given in Fig. 2. The same data are plotted in Fig. 3 with, however, the horizontal axis as the sensation level (db above threshold) of the masking tones.

From Fig. 2 it is clear that, _if_ threshold of detectability is a valid criterion of speech intelligibility, then, (1) the effective range of pure tones when presented alone is relatively small, and (2) linearity of the growth of interference is related to frequency. The lower the frequency, the greater the departure from linearity.

Figure 3 is plotted on the assumption that (a) the listeners have normal hearing and (b) that acuity at the two ears at any frequency is different. The binaural threshold used for calculating the sensation levels of the masking tones is then equal to the normal MAP (from Sivian and White). The curve shows that the degree of masking at any sensation level is inversely related to frequency of the tone from 100 cps.

One of the difficulties in evaluating the data as presented is to determine the relation between sentence detectability and PB word list detectability thresholds derived from other studies. Comparison with the temporary effects of exposure to high level pure tones confirms, however, the inverse relation of speech hearing impairment to frequency of the exposure tone, down to 500 cps, articulation loss being measured by Harvard PB word lists (% correct). The loss is most clearly related to the "overall loudness-loss at the intensity level at which the speech is heard."[19/] This would imply rapid growth of intelligibility beyond the level of TTS. The same thing should be observed for masking, if, as seems likely, masking and TTS produce similar limitations on the ears' operation at above "threshold" levels.

3. Masking of Pure Tones by Narrow Bands of Noise

As noted by Bilger and Hirsh,[12] values for masking of pure tones by narrow bands of noise have been derived in the main from studies of white noise and only partly subjected to empirical test. In 1937 Fletcher and Munson[13] carried out experiments in which the noise was tailored to produce equal masking at all frequencies. In 1940 Fletcher postulated that there is, for every frequency, a band of noise the widening of which will not increase masking of the pure tone at its center frequency. This was called the "critical band." Hawkins and Stevens[14] investigated the masking of pure tones by white noise in 1950 and determined values of the critical band so defined by the rational procedure of assuming that the ratio of a pure tone to the energy per cycle of white noise at its masked threshold equals the ratio in db of the frequency band, necessary and sufficient to mask it when the overall energy in the band equals that of the pure tone (at its center frequency).

Bilger and Hirsh point out that the critical band has had three definitions. It is the minimum bandwidth (1) effective in masking any given pure tone; (2) whose overall energy equals that of a pure tone at its center frequency when the pure tone is barely masked; and (3) whose absolute threshold equals that of a pure tone at its center frequency.

For the critical band hypothesis to be confirmed all these features of it should coexist. Adequate test would require:

a. Determination of the relation between bandwidth and spectrum level of white noise at threshold.

b. Information on threshold values for pure tones.

c. Determination of that combination of bandwidth and spectrum level which

(i) is equal in overall energy to threshold for a pure tone at its center frequency,

(ii) is at threshold, and

(iii) barely masks the pure tone at threshold.

The necessity for all features to be present is due to the possibility of a number of combinations of bandwidth and spectrum levels of equal overall energy and at threshold producing different masking effects on a specified pure tone at their center frequency. Such bands should show:

(1) Linearity of masking of the pure tone with spectrum level (bandwidth constant).

(2) Independence of masking from increased bandwidth, spectrum level constant.

(3) A linear relation between narrowing of bandwidth and masking with spectrum level constant.

Partial test of the first feature of the hypothesis was provided by Shafer et al.[15] Critical bandwidths in frequency were obtained and a level of constant masking reached for bandwidths with center frequencies at 200, 800 and 3200 cps. An arbitrary maximum was extrapolated from each curve to derive relatively narrow critical bands. Data for other levels and frequencies were not obtained. In general, the data on bandwidth were consistent with the method of Fletcher and Hawkins and Stevens in deriving the bandwidth from energy ratios of tone and spectrum level of the noise at masked threshold.

Hirsh and Bowman[16] in a study on the effect of narrow bands of noise on speech provided a test of the "equal energy at threshold" part of the hypothesis. Threshold measurements of eleven 250 mel-wide bands of noise were made. The sum of the levels per cycle in db and the critical bandwidths were plotted against the MAP curves of Sivian and White. A close correspondence between the noise band threshold levels and the MAP curves was found at the center frequencies.

Bilger and Hirsh[12] confirmed the implication of linearity for peak levels of noise within the critical band. The degree of masking closely follows the filter characteristics for tones close to the center frequency. However, nonlinear masking is produced at frequencies above and below the band.

An interesting consequence of the Bilger and Hirsh investigations was the discovery of "remote" masking (constant for any given noise level at low frequencies). This observation led to the hypothesis that the low frequency masking is due to rectification and detection by the ear, operating as a nonlinear system, of the envelope characteristics of the noise. Subsequent test of this hypothesis by Deatherage et al led (a) to confirmation by control of the frequency of remote masking by the noise envelope[4] and (b) observation (on guinea pigs) that a high frequency band of noise produces an apical cochlear microphonic at high levels of the noise.[5] The ability to control the frequency location of the remote masking is strong confirmation of the correctness of their guess. Spieth[17] was able to locate the difference tones produced by two tones in the region of low frequency "remote" masking. That combination of tones can account for low frequency masking effects beyond the limits of the noise as well as at high frequencies has some plausibility; however, the degree of masking is less than that which would be "predicted from the critical band levels of the aural difference tones."

4. Masking of Speech by Noise

Masking of speech by narrow bands of noise with articulation score as the dependent variable was reported by Miller in 1947.[18] Only two of 8 narrow bands produced complete (100%) loss at a speech level of 95 db. Masking was complete also at high levels of wide band noise (20-4000 cps).

Miller points out that, as the level of the noise in any narrow band rises, a point should be reached beyond which intelligibility is not further impaired, and that this occurs for high frequency bands. For low frequency noises, however, the impairment increases to total articulation loss. This is explained by the spread of masking from low to high frequencies with increased level.

Hawkins and Stevens[14] studied the effect of wide band noise on the threshold for intelligibility and detectability of connected discourse. Their findings were:

1. Both thresholds are raised by an amount roughly equal to the increment of noise at all but the lowest noise levels.

2. The difference between thresholds of detectability and intelligibility diminished by 4.5 db from the lower to the higher noise levels.

3. Masking of speech is most closely related to masking of 500, 1000 and 2000 cps.

Hirsh and Bowman[16] studied the effect of eleven bands of noise 250 mels wide and of white noise on the threshold of intelligibility of spondee words. The results of these studies confirm that, as might be expected, white noise is the most effective masker. Extreme high (5100-6600) and low (20-160 cps) bands were least effective. Further results were:

1. The linear relation of threshold shift to noise level is present only in the mid-frequency bands. The two low frequency bands show negative acceleration, the high frequency bands positive acceleration of threshold shift with increased noise level.

2. Bands in the mid-frequency range are the most effective in raising spondee thresholds. The authors derive curves relating frequency to noise level per cycle and comment (a) that for bands of noise the most effective is somewhat higher in (center) frequency than the pure tone data of Stevens et al[11/], and (b) there appears to be no shift to the low frequencies as level is raised. This is presumably due to the absence of intra-aural harmonics and combination tones at high level sufficient to change the masking pattern for low frequency sounds (see Bilger and Hirsh[12/]).

Generalization from threshold findings for sentences and spondee word lists to PB articulation loss would require that the following assumptions be true. (1) The difference between thresholds, e.g., spondee and PB word tests are stable from one set of experimental conditions to another (subjects, apparatus, word lists), (2) this relation is not dependent on noise spectra, and (3) threshold shift is comparable to that produced by conductive type deafness, i.e., it represents a shift of the curve relating word score to speech SPL without change in its shape. Unfortunately (a) the relations between even different types of threshold (e.g., detectability and intelligibility) for the same speech material and noise varies with the noise level; (b) noise operates to change the shape of the articulation function so that threshold shift is not proportional to the speech level necessary to produce maximum articulation; and (c) there is no evidence for a stable relation between thresholds among different noise spectra.

NEW EXPERIMENTS

The studies we conducted are concerned primarily with the masking of low frequency pure tones on pure tones and speech. Experiment I deals with masking of pure tones by tones ranging from 50 to 8000 cps; Experiment II with articulation loss due to masking by pure tones from 50 to 200 cps; Experiment III with the masking of pure tones by narrow bands of noise.

Experiment I.

Apparatus and Technique

Continuous threshold curves of three subjects were taken monaurally before and during exposure to the masking tones. A modified Bekesy type audiometer was used (Grason-Stadler type E800), the threshold indicator being a continuous line drawn through the midpoints of the excursions. Masking tones were generated by a beat frequency oscillator (General Radio 1203-A) mixed with the audiometer tone, and fed through a 160-watt power amplifier (Stromberg-Carlson type AP-80) and 150-watt power attenuator to a small speaker (KLH 6.5). This speaker was mounted on an earmuff headband (Willson "sound barrier" model 258) and a cushion from the same earmuff attached. For high levels of the masking tone (greater than 75 db) a tone of the same frequency, 10-15 db lower in level, was presented to the contralateral ear. The apparatus used here was a power amplifier (Altec 165-watt, model 1570-A), and a power attenuator and earphone similar to that used for the test ear.

The level of the masking tone was calibrated on a dummy head using an Altec type 21 BR microphone and General Radio Sound Level Meter type 1551-B. Calibration of the sound level meter was carried out with BBN acoustic calibrator No. 308C-9 During measurement of the masking tone the microphone was positioned inside the dummy head, inclined slightly up and to the rear of normal to the speaker diaphragm, and about 9 mm from its central surface in the region of the "tragus." Frequency response curves of the KLH speakers are given in Fig. 22.

Masking frequencies and levels are given below (Table 1). Reference thresholds used to determine the masking pattern were in all cases taken immediately before testing at any frequency and level of the masking tone. In most instances (excepting the lower levels) a test session consisted on one audiogram without, and one with, the masking tone. For frequencies of fp up to and including 400 cps additional audiograms are used before, and during, exposure to fp. The audiograms over the frequency range 40-160 cps were obtained with the rate of frequency change on the Bekesy audiometer set at one minute forty seconds per octave (instead of 2 octaves per minute as for the audiograms in the 100 to 10,000 cps frequency range). The attenuation rate of the Bekesy audiometer was 2 db per second.

Instructions to the subjects were to push (or release) the audiometer control when they were "reasonably sure" they could (or could not) hear the tone from the audiometer. All subjects had normal hearing to 10,000 cps in the test ear. Two subjects were experienced in participating in psychoacoustic experiments. The other had had some experience of audiometry prior to testing.

Results

Table 1 presents data for the calculation of the sensation levels of the masking tones. The method was to take a reference level of the masking tone in SPL by means of SLM (sound level meter, "C" scale, meter on "slow") readings obtained with the earphone on the dummy head. The audiometer chart was "calibrated" in terms of

TABLE 1

SPL and Sensation Level of Masking Tones

Frequency	Mean Threshold (SPL)	SPL (SLM)	Sensation Level
50 cycles	53	75 100 125	22 47 72
100 cycles	40	75 100 125	35 60 85
200 cycles	30	75 100 110	45 70 80
400 cycles	19	75 100	56 81
1000 cycles	7	75 100	68 93
2000 cycles	12	75 100	63 88
3000 cycles	15	75 90	60 75
4000 cycles	17	75 90	58 73
8000 cycles	29	75 110	46 81

absolute SPL values on the basis of the sound level meter readings. Sensation level is then the sound pressure level of the masking tones used, less the mean threshold value.

Masking curves are given in Figs. 4-12. The parameter is SPL (sound pressure level) of fp (frequency of primary or masking tone) with sensation level, db re mean threshold for three subjects, in parentheses.

The level of the masking tones (at 75 db and one or two of 90, 100, 110 and 125 db) leads to some difficulty in making comparisons between our data and others', and between frequencies of fp within our data. However, the following general conclusions are warranted:

(1) They are asymmetrical, masking of fs higher than fp being greater than for fs less than fp. This is true of all the curves with the possible exception of the 35 db SL (sensation level) at 100 cps. The result is not unexpected since (a) in previously reported data, 40 db SL is the minimum for clear asymmetry to emerge, (b) it is related to level of the masking tone, (c) inversely related to its frequency, and (d) our combinations of frequency and level of fp show in general higher SLs with increasing frequency. The minimum SL used is 35 db.

(2) The degree of maximum masking is linearly related to level of the masking tone at fp 50 and 100 cps. At the other masking frequency where three levels were used (200 cps), the function is very nearly linear, but may become positively accelerated at high levels. Data from the other curves indicate that the slope of masking versus level of the masker is inversely related to frequency of the masking tone at sensation levels from 40-80 db (Figs. 16-17).

A characteristic feature of the curves for fp less than 1000 cps is that the point of maximum masking occurs above fp, and shifts higher with increased level. With the exception of 2000 cps at 88 SL, all the curves for fp 1000 cps and above show maximum masking at fp. The frequency difference between fp and the point of maximum masking is much greater than the 1 - 2% frequency error from the oscillator and oscillator-recording pen. A possible explanation is that it follows from a "dip" at fp equal to fs due to beats, and that these occur at the low frequencies of fp only, because of the use of a slow rate of frequency change in the 40-160 cps masking audiogram. However, (a) Ehmer finds no evidence of "dips" using a similar slow rate of frequency change, and (b) the point of maximum masking for fp's of 200 and 400 cps is similarly above fp, in our data. If this peak be regarded as corresponding to Ehmer's second peak, then the data do show more agreement with Ehmer's, i.e., the second peak becomes the point of maximum masking at low frequencies of fp (Ehmer Figs. 1-2).

Data from the present study are plotted together with data from Wegel and Lane[6/] (Fig. 13), Egan and Hake[10/] (Figs. 14-15), and Ehmer[8/] (Figs. 18-19).

The data by Wegel and Lane for 200 cps are "blown up" from curves by Fletcher.[7/] Direct comparison is possible only at 80 db sensation level.

The overall amount of threshold shift from 200 cps, the frequency of the masking tone, to 5000 cps, the upper limit of Fletcher's plot is about equal for the two curves, the mean absolute deviation being only 2.6 db for 18 intermediate frequencies. However, there appear to be systematic differences within the range of frequencies mentioned. From 200-300 cps the curves from Wegel and Lane show less shift than those from the present study. Between

1-3 kc this is reversed, while beyond 5 kc the extrapolated curve of Wegel and Lane again falls below our data. The maximum difference is 8 db for the obtained curves and about 9 db for the extrapolated curve. In general our data show more masking at frequencies lower than the masking tone than Wegel and Lane's.

These differences are difficult to evaluate since (a) ours are the mean of only three observations and (b) Wegel and Lane tested for masking at only eight or nine discrete frequencies. The result suggests, however, that degree of masking, integrated over all test frequencies has considerable invariance, regardless of technique.

The amount of masking below the frequency of a masking tone of 400 cps is much the same in our data and Egan and Hake's (Fig. 14).

Figure 15 shows pure tone and narrow band noise masking from both experiments. Continuous curves are from Egan and Hake for a noise band 90 cps wide. The long dashed curve is their pure tone data, at 400 cps. The dotted curve is visually interpolated to correspond to 75 db OA noise. This curve crosses our 75 db pure tone curve in about the same way as the 80 db noise curve crosses that of Egan and Hake for an 80 db pure tone. This confirms the general agreement between the two studies.

Figure 18 compares pure tone masking at fp 1000 cps from our data and Egan and Hake's. The general similarity of the curves is obvious, e.g., in the presence of second and third peaks at higher levels of fp and the rate of growth of masking at fp, diminishing with level of fp. Differences are (1) our data show more masking at higher frequencies of fs and levels of fp, (2) low frequency masking is more extensive, and (3) the second peak is shifted more toward the higher frequencies.

Experiment II

The purpose of the second experiment was to determine the effect of low frequency pure tones (50, 100 and 200 cps) on the perception of PB words. Two levels of speech were used to examine the effect of different masking patterns of pure tones at similar S/N ratios.

Apparatus and Technique

Recorded PB word lists (male voice) were replayed by Ampex tape recorder, Catalog No. 30950-2, Serial No. 110, fed through a 500 ohm attenuator and mixed with the oscillator tone in the same way as the audiometer tone in the previous experiment. The remainder of the apparatus was the same. Each subject, except for later stages of the study when exigencies of time prevented it, was presented with each tone-speech level combination twice, using different word lists for each condition. Again, although there were departures later, the same word list was used for each tone-speech combination with another subject. The order of presenting tone level with speech was counterbalanced for any given frequency of the tone. Full data on subjects, speech and tone levels are given in Table 2 (Experiment II). The use of 0 level tone in the experiments was (1) to determine practice effects, (2) to provide a reference for comparison with mixed pure tones and speech, and (3) to ascertain whether or not a preceding exposure to high level pure tones and speech had affected speech hearing.

The subjects were young graduate and undergraduate college students, each of whom had had a minimum of 10 hours testing with PB word lists under a variety of experimental conditions. The word lists used were different "scramblings" of those heard under the other conditions. All subjects had normal hearing from 100 to 10,000 cps. No attempt was made to balance the sequence of testing by speech

TABLE 2 (Experiment II)

Oscillator Frequency	SPL of Masking Tone	SL of Masking Tone	OA Speech Level
50 cps	0 db	0 db	100 db
50 cps	120 db	67 db	100 db
50 cps	135 db	82 db	100 db
50 cps	0 db	0 db	75 db
50 cps	95 db	42 db	75 db
50 cps	110 db	57 db	75 db
50 cps	123 db	70 db	75 db
50 cps	133 db	80 db	75 db
100 cps	0 db	0 db	100 db
100 cps	110 db	70 db	100 db
100 cps	130 db	90 db	100 db
100 cps	0 db	0 db	75 db
100 cps	95 db	55 db	75 db
100 cps	105 db	65 db	75 db
100 cps	110 db	70 db	75 db
100 cps	120 db	80 db	75 db
100 cps	130 db	90 db	75 db
200 cps	0 db	0 db	100 db
200 cps	105 db	75 db	100 db
200 cps	115 db	85 db	100 db
200 cps	130 db	100 db	100 db
200 cps	0 db	0 db	75 db
200 cps	80 db	50 db	75 db
200 cps	90 db	60 db	75 db
200 cps	100 db	70 db	75 db
200 cps	110 db	80 db	75 db

level since (a) the original subjects were unable to complete all test sessions and (b) it was considered that with pretrained subjects learning and fatigue effects would be restricted to within sessions.

Results

The dependence of articulation on SPL of the masking tone is plotted in Fig. 20 for both speech levels, with fp as the parameter. S/N ratios for the speech level are given on the graduated scales at the top of the chart.

For equal SPL of fp and both speech levels, 200 cps is the most effective masker, 50 cps the least effective. Total articulation loss (100 db speech) is not achieved by any frequency at SPL's up to 130 db. The same applies to 50 and 100 cps fp for speech level 75 db. Fp 200 cps, 130 db was not used for 75 db speech; however, it appears that the curve for this frequency reaches an asymptote at 100 db (25% articulation).

Figure 20 also indicates considerable differences between articulation scores at similar S/N ratios but different absolute SPL's of fp. At fp 200 cps, for example, an S/N ratio of -10 will induce 52% articulation loss (48% articulation) when the absolute level is 110 db, or about 10% loss when its level is 85 db. These differences become progressively less, however, as the S/N ratio is further reduced. At -30 S/N, the articulation scores are about equal. The same is true of other frequencies of fp.

The explanation for this is not difficult to find in the rapid increase of extended masking with increased level. It is probable also that a combination of distortion products produced by high level speech with those due to the tone could account for the drop in articulation at 0 S/N, 50 cps fp and 100 db speech.

Figure 21 gives articulation by sensation level of the masker. Here the pattern is less clear. At low sensation levels 50 and 100 cps produce the most decrement -- although the difference between 100 and 200 cps may not be significant. At high sensation levels of fp and the same (75 db) level of speech, both 100 and 200 cps cross the 50 cps curve and re-establish the order of masking effectiveness present in Fig. 20. This would follow from (a) the inverse relation between fp and the rate of increase of extended masking, and (b) the number of critical speech frequencies affected by a 50 cps tone being less than for the other two, especially on the low frequency "side."

If the above explanation is true, however, some other principle must be invoked to explain the curves for speech SPL 100. Here 50 cps crosses and 100 cps appears about to cross the curve for 200 cps fp. The answer may be in the greater number of harmonics generated in the ear by lower frequency tones, and their combination with the high speech level.

Experiment III

Masking of Pure Tones by Narrow Bands of Noise

Irregularities in the masking curves of pure tones are frequently attributed to perceived beats and combination tones between the masked and masking pure tones.[10] To determine the spread of masking function with beats, combination tones, etc. eliminated (as far as possible) a third study was carried out in which the masked signal was a pure tone but the masker consisted of a narrow band of noise. As in Experiments I and II the audiometer was a Grason-Stadler Bekesy, but only "descending" thresholds -- the masked tone gradually changed from a high to lower frequency -- were obtained in Experiment III.

The masking stimuli were six narrow bands of noise, 100 cps wide, presented at each of two levels. SPLs and frequency limits between the 3 db downpoints are given in Table 3. Details of apparatus and procedure follow.

Table 3. Bandwidths and Levels of Masking Noise

Noise No.	Band	SPL re .0002 Microbar	
1	75-175 cps	90 db	120 db
2	150-250 cps	90 db	120 db
3	350-450 cps	85 db	115 db
4	950-1050cps	80 db	110 db
5	1950-2050cps	70 db	100 db
6	3950-4050cps	70 db	100 db

The six bands were prerecorded on Ampex recording tape. White noise was also recorded both with and without the narrow band and at 40 db below the overall level of the band. Separate tapes were used for each band to enable ample time for a 100-10,000 cps audiogram to be made for each white noise, and white noise with narrow band condition.

Two audiograms for each of the twelve experimental conditions were taken. The audiometer range was 100 to 10,000 cps in each case. The first audiogram in each session served as a reference audiogram. The recorded white noise was included to provide a noise floor free of the pure tone components produced by the apparatus. The second audiogram of each session was done with the narrow band noise mixed with the audiometer tone. White noise masking was also introduced in the contralateral ear in cases where cross-hearing was likely, i.e., in the higher levels of the masking bands.

Three experienced subjects were used under all experimental conditions. The instructions were to operate the audiometer switch only when reasonably sure that the tone heard was from the audiometer and not a distortion product. The instructions thereby differed from those given the subjects in Experiment I. The same ear of each subject was used throughout.

In preparing the tapes, the white noise was recorded separately from the bands of noise. The output from a Grason Stadler noise generator was led to a 600 ohm attenuator and Ampex tape recorder. The narrow band noise was obtained by passing the output of the noise generator first through a Spencer Kennedy Model filter set for the band pass condition before proceeding to a 600 ohm attenuator and further filtering by a sharp crystal filter. The cutoff characteristics of the crystal filter are given in Fig. 23.

In the experimental session the output of the tape recorder was led to a 600 ohm attenuator, mixed with the audiometer tone, and fed to earphones by way of a model 100 Burr Brown voltage amplifier, McIntosh model MC-30 power amplifier, 150 watt power attenuator and finally to one of a pair of HA-10 earphones. The pure tone output of a Grason Stadler type E-800 audiometer was led to a GR unit amplifier type No. 410 and 600 ohm attenuator before being mixed with the recorded noise. Masking for the contralateral ear was provided by linking the other earphone directly to the audiometer masking noise generator. This was easily done since the impedance of the HA-10 earphone is very similar to the standard TDH-39. Fig. 24 gives a block diagram of the arrangement of the playback equipment.

Results

The results of Experiment III are presented graphically in Figs. 25-36. Each curve is the average threshold shift over three subjects due to (a) the white noise "floor" and (b) the narrow band and white noise floor combined. Several general features of these masking curves are apparent.

(1) Growth of the level of maximum masking with level of the masking noise is roughly linear with a slope of one. There are some departures from this but no consistent trend is apparent.

(2) Unlike our pure tone data, the point of maximum masking is closely tied to the center frequency of the masking and shows little tendency, except in perhaps the highest band (3950-4050 cps) to shift upwards with higher levels of the masker. Except with the 75-175, 150-250, and 3950-4050cps bands (the bandwidth are designated to the 3 db downpoints on the filter skirts, see Fig. 23) the band point of greatest masking appears slightly below the center frequency of the masking noise.

(3) The curves are markedly smoother than those for pure tones. However, irregularities are not completely eliminated, and in curves for 15-250, 350-450, 950-1050 cps masking noises (Figs. 27-32) there appears a small second peak, more marked at higher levels. A comparison of the masking due to our 350-450 cps band and Egan and Hake's 90 cps wide band, centered at 410 cps, indicates considerable agreement in the slopes of the spread of masking both above and below the noise band (Fig. 37). Failure of the curves to coincide more closely is due to a bodily shift of our curve 100 cps down, and also to a difference in maximum masking. Our curve lies below Egan and Hake's by 3 db, even though the overall level is 5 db higher.

Before concluding that a real difference exists in the frequency of the masking curves shown in Fig. 37, it appeared necessary to examine the original recordings for an error in center frequency. This was checked by replaying the recording of the 150-250 cps band and measuring its level in 25 cps bands. The check showed that the apparent shift in the masking curve, relative to Egan and Hake's results, was probably due to other causes than the recording apparatus.

It is possible that the difference between Egan and Hake's curve and ours could be attributed to the different audiometric techniques used in the two experiments: Egan and Hake used a fixed-frequency probe tone for measuring threshold shift, whereas we used the Bekesy audiometer with a constantly shifting frequency. Conceivably a slight delay in the subject's "tracking" the tone in the vicinity of the masking noise while getting a "descending" threshold, the type obtained in this study, would result in an apparent downward shift of the masked threshold.

DISCUSSION

The two major purposes of these experiments were to study the masking effects of very intense, low frequencies on pure tones and speech and to gather information that would be useful for formalizing the general pattern of the upward spread of masking, particularly as it might apply to speech interference.

Attempts have been made to develop from the data on the masking of pure tones by pure tones a procedure whereby one could convert the physical spectrum of a complex sound, such as a band of noise, into the "masking" spectrum of that sound. A knowledge of the masking spectrum of a noise is of use in calculating by means of the "Articulation Index" what the intelligibility of speech will be in the presence of that noise.

A previously used method of deriving this desired procedure has been merely that of estimating the average slope of the upward spread of masking curves found with pure tones at various frequencies and sensation levels. Plotting a straight line to fit the course of the upward spread of masking by pure tones is, however, not easy to do. In the first place there are some differences among the results obtained by different investigators on the upward spread of masking. Secondly, the actual masking curves change their slopes, both positively and negatively, several times in their course.

Drawing a straight line through the spread-of-masking contours may be justified on the grounds that sharp peaks and valleys in these contours are to some extent at least "artifacts." By this we mean that "beats," "roughness," and other changes in the subjective character of one pure tone in the presence of another harmonically and near harmonically related pure tone disturb the perception of the true masked "threshold." Presumably the masking of a complex sound, such as speech, with continuously changing phase relations among its components or, conversely, by a complex sound or noise with continuously changing phase relations among its components would not be subject to at least all of the irregularities exhibited by the pure tone masked thresholds. It may be, then, that some of the phenomena observed in masking by pure tones are not appropriate features to be measured when attempting to predict the masking of waveform such as speech in which the phase relations of the components are complex and changing. It was, of course, for this reason that Experiment No. 3, the masking of pure tones by narrow bands of noise, was conducted.

If we compare the results of Experiments 1 and 3 we find that the upward spread-of-masking contours due to a band of noise are indeed smoother, but, of more importance, fall off -- show less masking -- at a greater rate at the higher frequencies than do the contours from a pure tone of the same center frequency. This can be seen graphically in Fig. 38.

Although some of the difference in irregularity between the masking contours from the band of noise and the pure tones could be due to differences in the instructions given to the listeners (see instructions to subjects - Experiment 3) the difference in apparent masking effectiveness is perhaps surprising; one would expect, we think, that the depression of the threshold shift due to the presence of beats, difference tones, etc., would tend to lower rather than elevate the general position of the pure tone masking contours.

In any event the depicted upward spread of masking is less when obtained by a narrow band of noise than by a pure tone of similar center frequency.

A pertinent question to be asked is whether the upward spread of masking should be related to the center frequency of a band of noise or to the upper edge on the frequency scale of the band of noise. This is another way of asking what, if any, is the effect on the upward spread of masking of the bandwidth of the masking noise. It is certainly reasonable to postulate that the upward spread of masking is more tightly controlled by the highest frequency or perhaps highest critical band than by the total bandwidth of the noise. (This seems to be the case for the downward spread of masking -- so-called remote masking.) We do not, unfortunately, have the necessary data at hand to answer this question.

Generalized Spread-of-Masking Contours.

Perhaps the most useful or practical way to plot the spread-of-masking data is in terms of the sound pressure level one sound must be in order to be heard in the presence of another sound of known frequency and sound level. Figures 39, 40 and 41 give such information on the masking of pure tones by narrow bands of noise.

We have interpolated and extrapolated with considerable liberty from the data on Figs. 39, 40 and 41 a general pattern for upward spread of masking effects of a band of noise. The results of our efforts are given in Table 4.

The validity of these contours can be examined to some extent by using them in calculating by means of so-called Articulation Index the speech intelligibility to be expected in the presence of pure tones and bands of noise and comparing the results of our calculations with the results of empirically obtained speech tests given in the presence of bands of noise.

We have used these masking contours in that way and found that calculated and measured speech intelligibility scores are in reasonable agreement with each other. The procedures used and the details of the test results and calculations are to be found in AFCCDD TN 61-35, The Validity of the Articulation Index.

An attempt was made to predict, by means of a calculated AI, the results of Experiment 2, the masking of speech by a pure tone. We estimated the masking spectrum by (1) an application of the spread-of-masking functions given in Table 4, and (2) by a direct application of the spread-of-masking contours found in Experiment 1, the masking of pure tones by pure tones.

Although the calculated AI's predicted the results for the different levels of the several masking tones fairly well, we were uncertain as to how best to plot the masking spectrum of a pure tone when it is used to mask a complex signal, such as speech. We believe that the development of a more proper and successful procedure for this purpose will require empirical test data that is not available.

Table 4

High Frequency Part of Masking Spectrum -- Upward Spread of Masking

A
Draw from Starting Point Horizontal Line to Right for this number of cps.

B
Draw from Right Hand End of Horizontal Line, a Downward Line that has this Slope in db per Octave.

Maximum Spectrum Level or Masking Level, whichever is higher, of Noise above 0.0002 Microbar in db	Frequency of Starting Point Located in Step 3									
	50-800 cps		800-1600 cps		1600-2400 cps		2400-3200 cps		3200-5200 cps	
	A	B	A	B	A	B	A	B	A	B
96 db - --	250 cps	10 db	500 cps	8 db	1000 cps	5 db	1500 cps	3 db	3000 cps	0 db
86 - 95	200	15	500	13	1000	10	1500	5	3000	0
76 - 85	200	20	400	18	800	15	1500	10	3000	0
66 - 75	150	25	250	23	500	20	1000	15	2000	5
56 - 65	75	35	150	30	300	25	500	25	800	20
46 - 55	50	45	100	40	200	35	200	40	200	40

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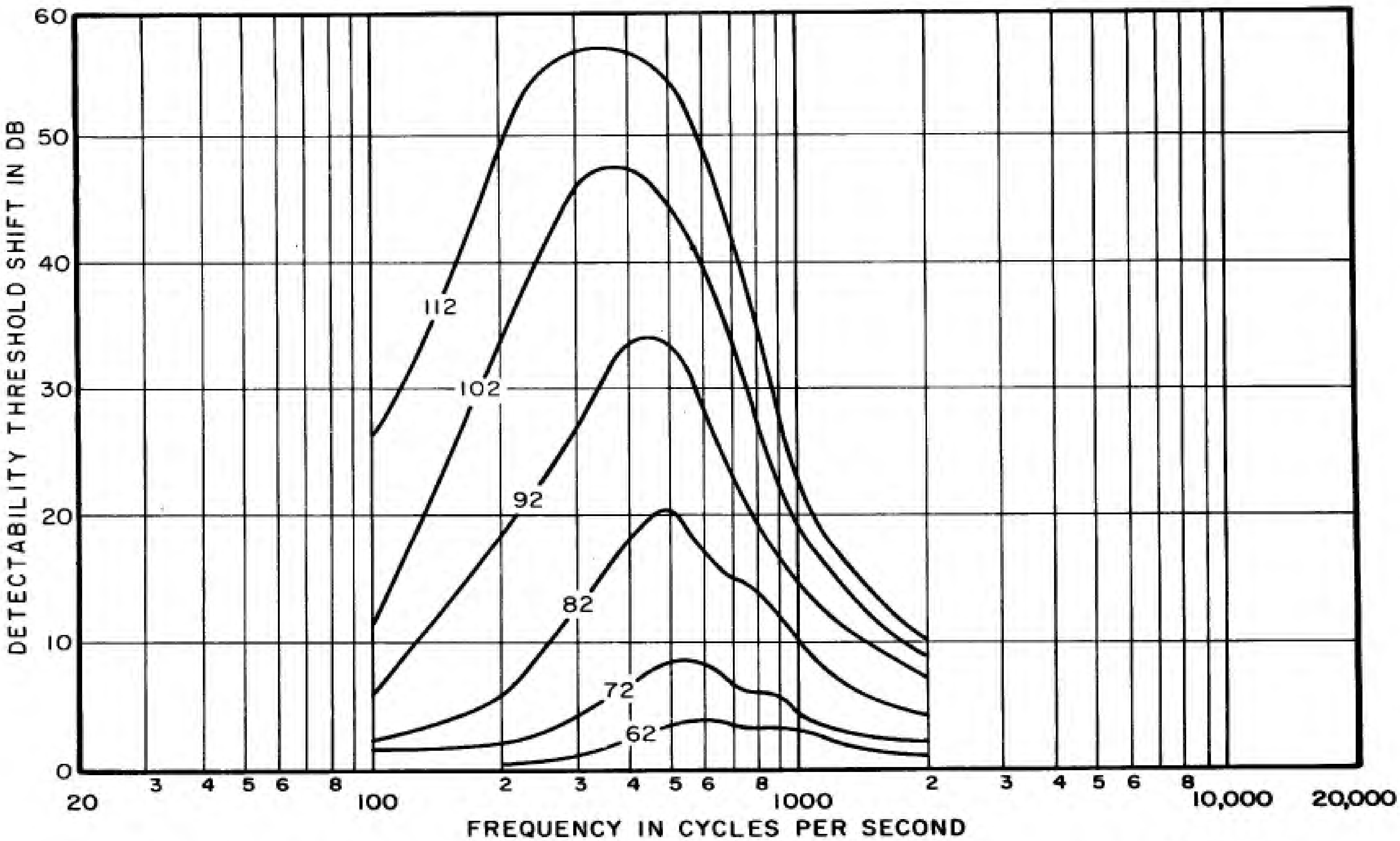

FIG. 1 DETECTABILITY THRESHOLD SHIFT AS A FUNCTION OF FREQUENCY OF THE MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE IN DB. (FROM STEVENS ET AL[11])

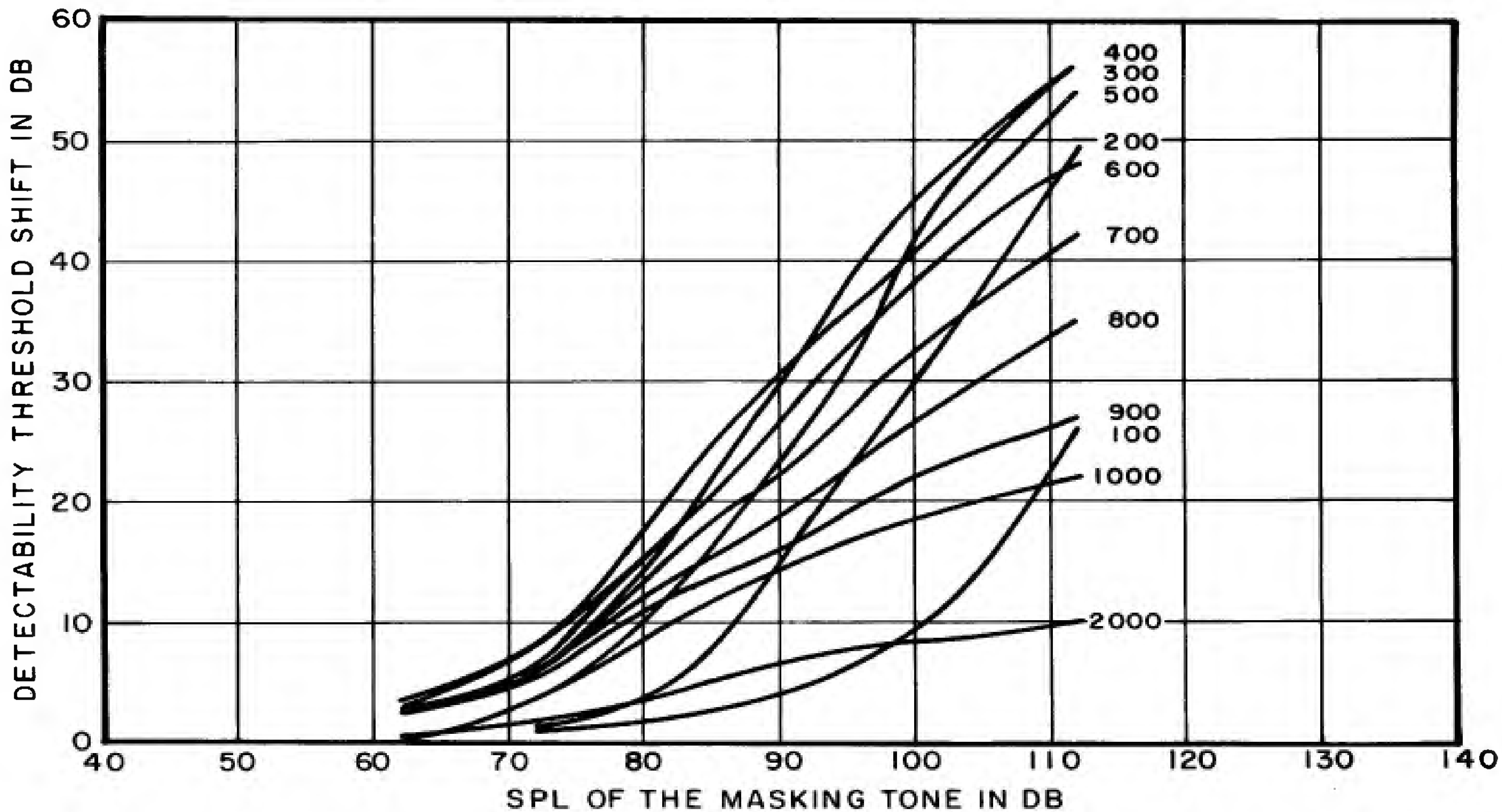

FIG. 2 DETECTABILITY THRESHOLD SHIFT PLOTTED AGAINST SPL OF THE MASKING TONE. PARAMETER IS FREQUENCY OF THE MASKING TONE.

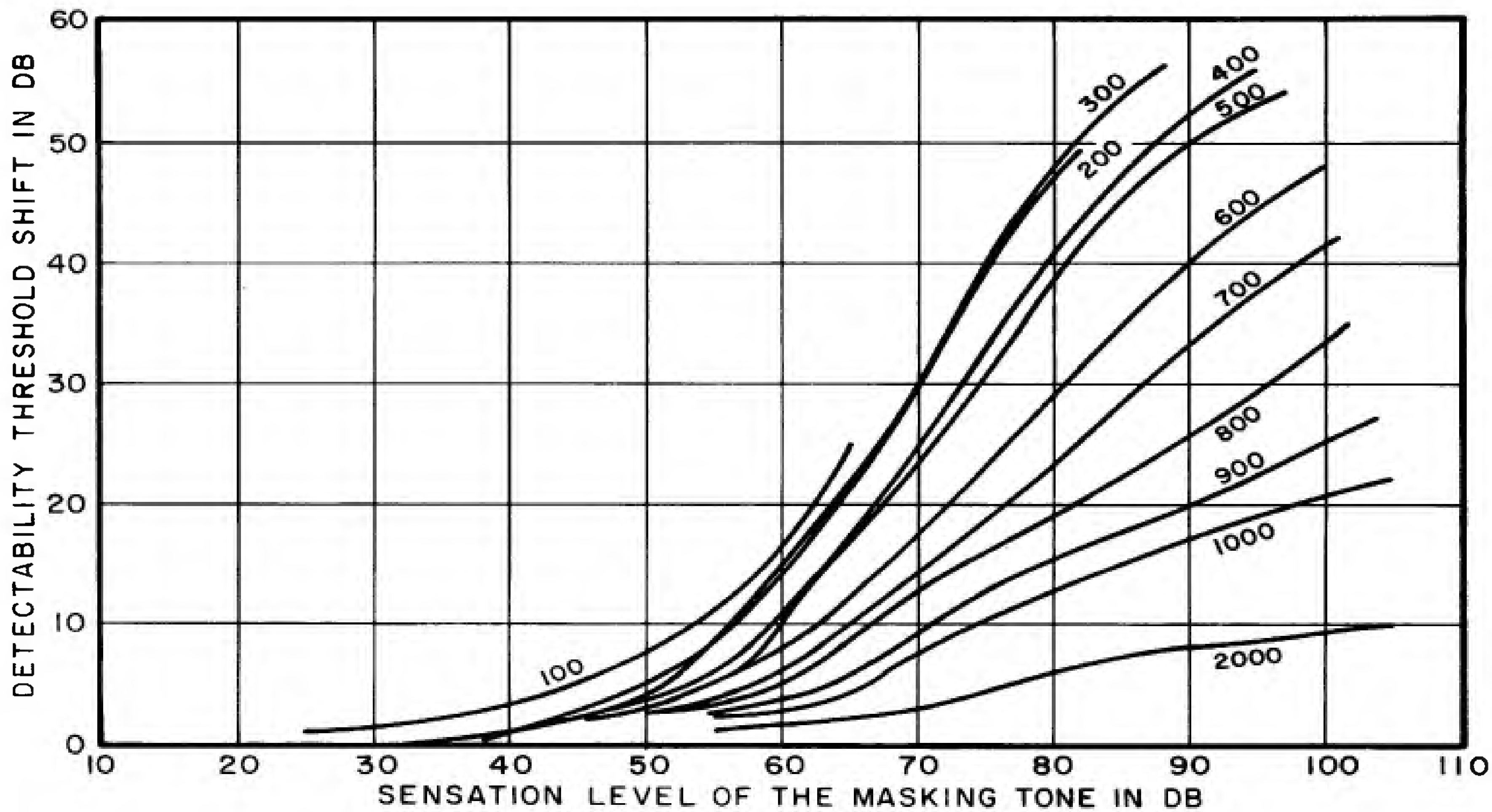

FIG. 3 DETECTABILITY THRESHOLD SHIFT AS A FUNCTION OF THE SENSATION LEVEL OF THE MASKING TONE. PARAMETER IS THE FREQUENCY OF THE MASKING TONE.

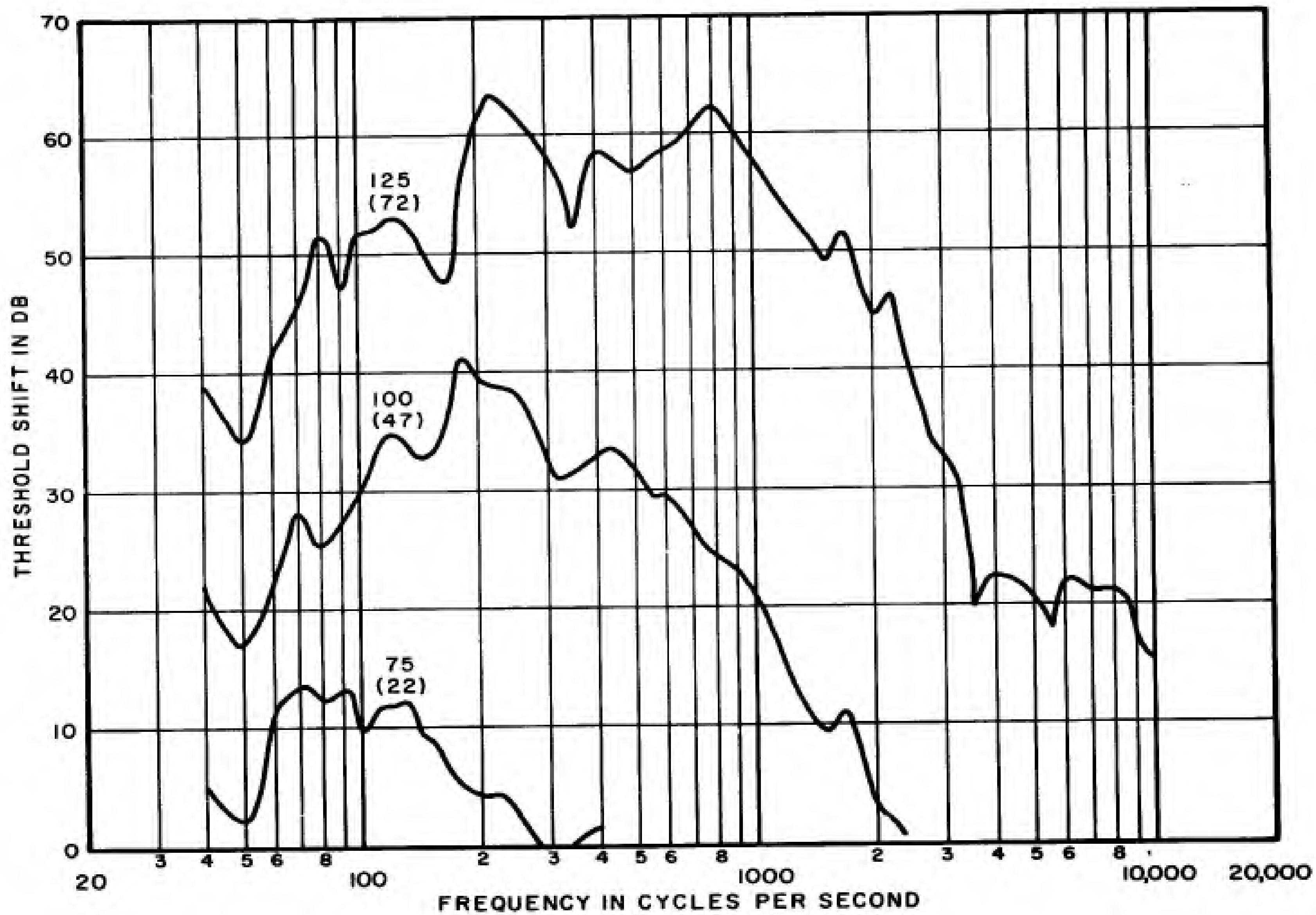

FIG. 4 THRESHOLD SHIFT DUE TO A 50 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE IN DB. SENSATION LEVEL IS IN PARENTHESES.

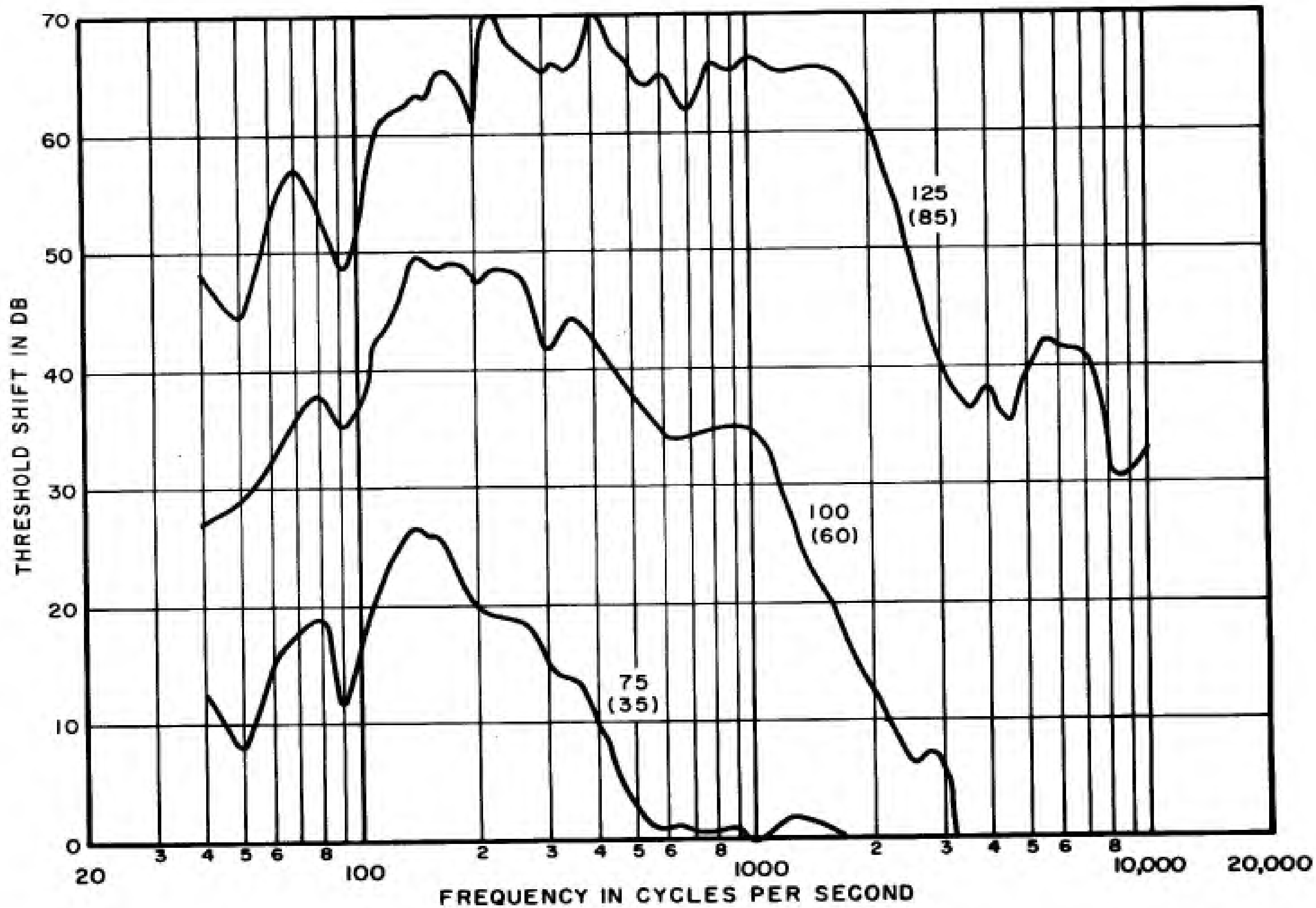

FIG. 5 THRESHOLD SHIFT DUE TO A 100 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE IN DB. SENSATION LEVEL IS IN PARENTHESES.

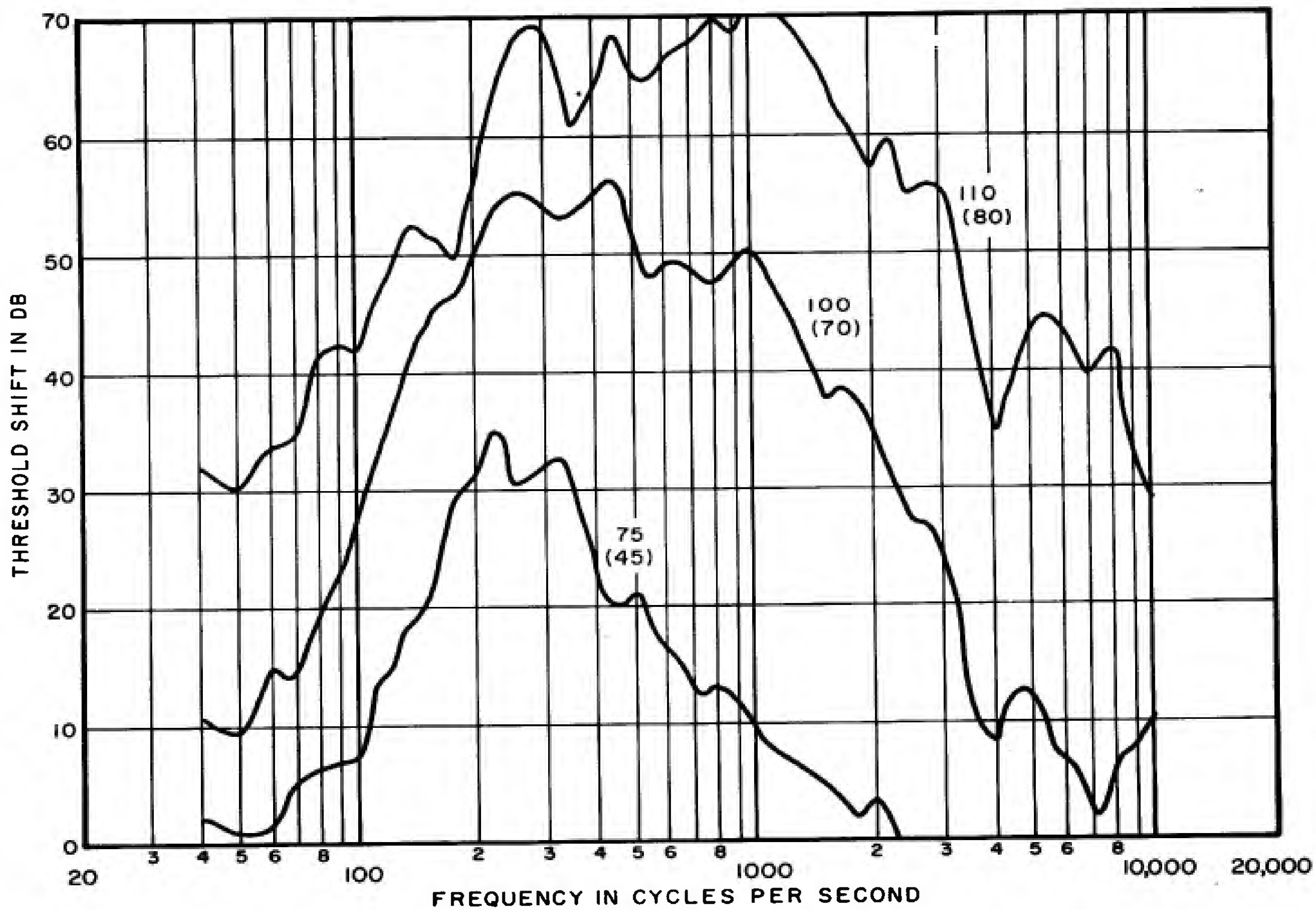

FIG. 6 THRESHOLD SHIFT DUE TO A 200 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE IN DB. SENSATION LEVEL IS IN PARENTHESES.

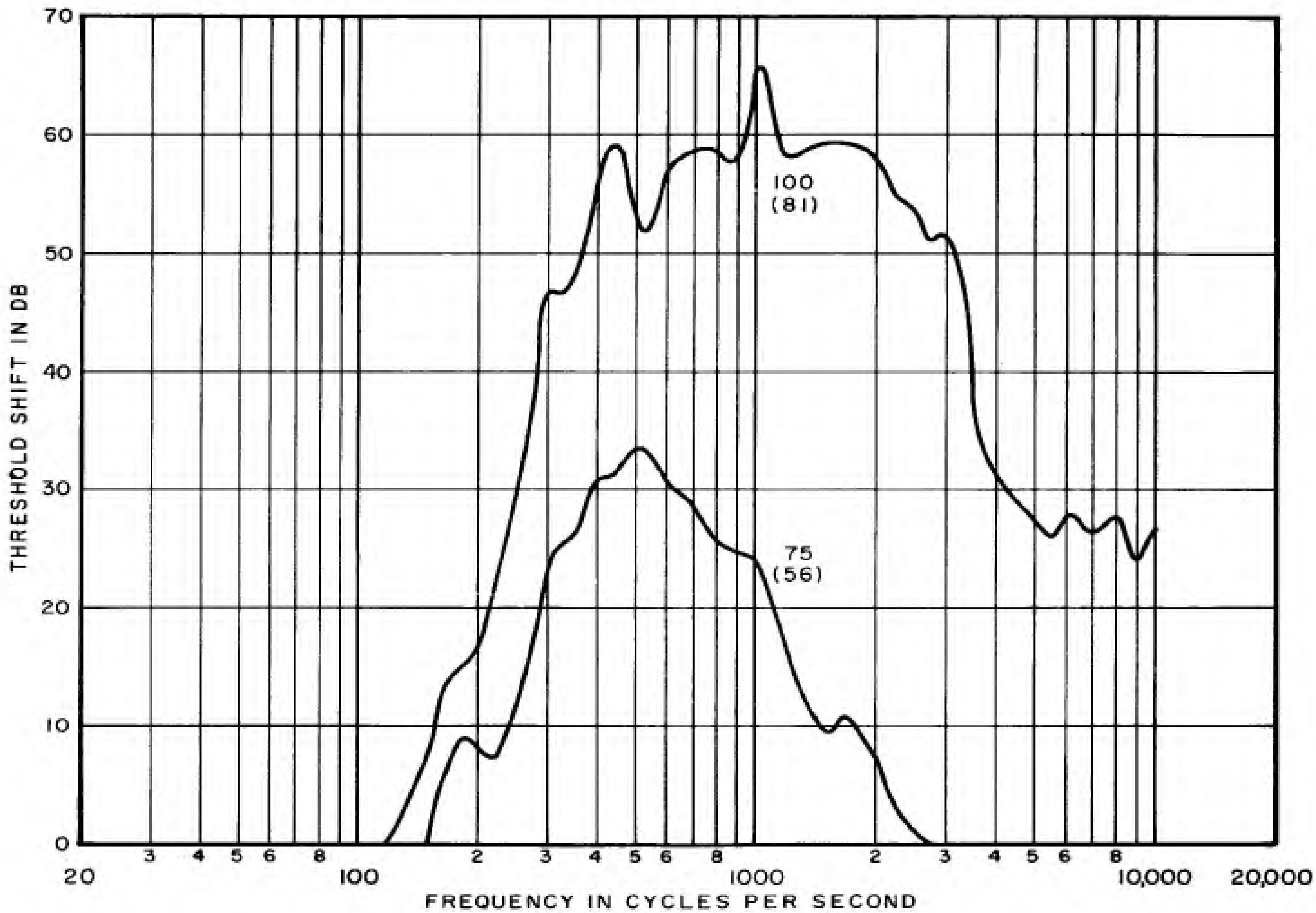

FIG. 7 THRESHOLD SHIFT DUE TO A 400 CPS MASKING TONE. THE PARAMETER IS THE SPL OF THE MASKING TONE IN DB. THE SENSATION LEVEL OF THE MASKING TONE IS SHOWN IN PARENTHESES.

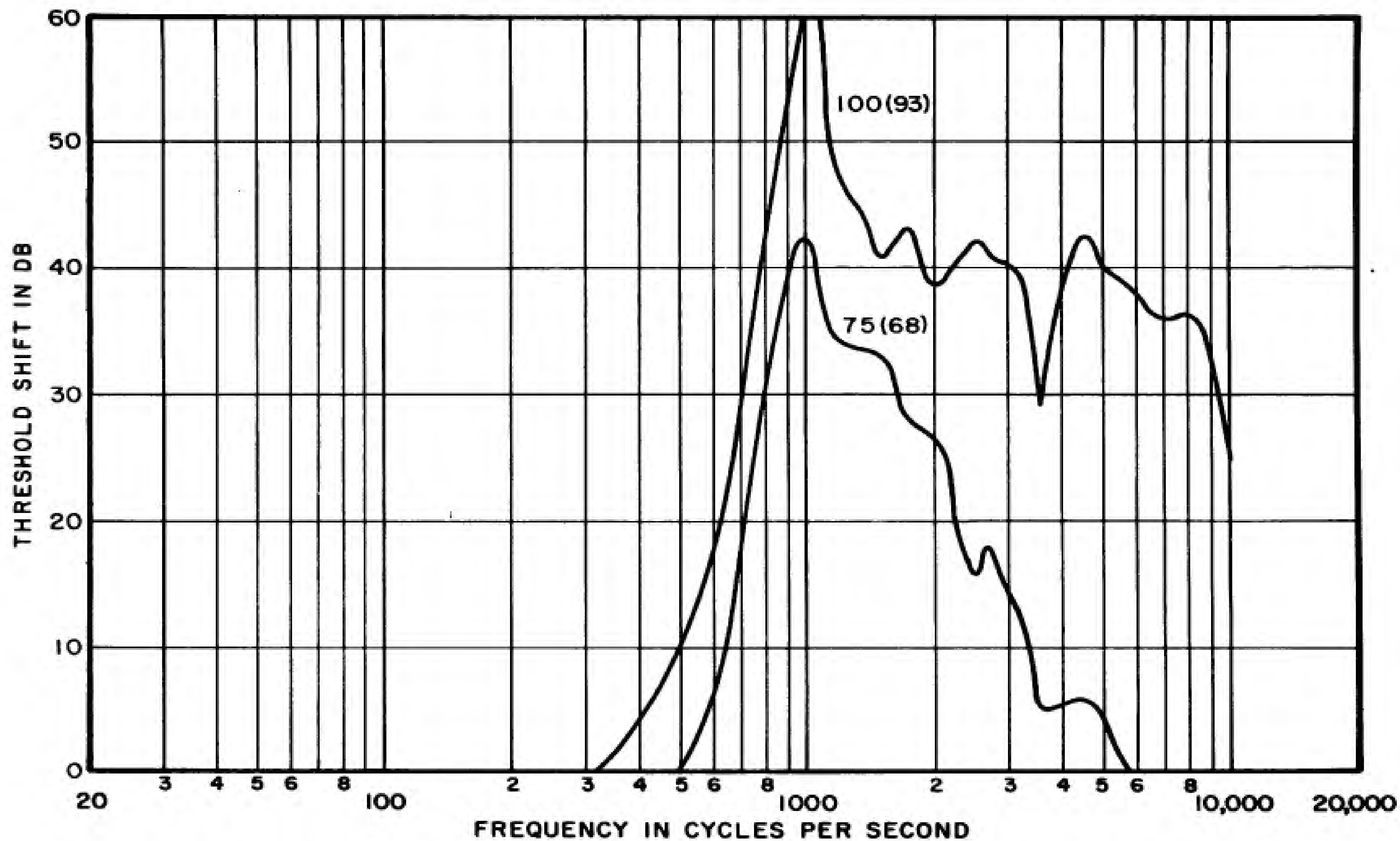

FIG. 8 THRESHOLD SHIFT DUE TO A 1000 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE. SENSATION LEVEL IS IN PARENTHESES.

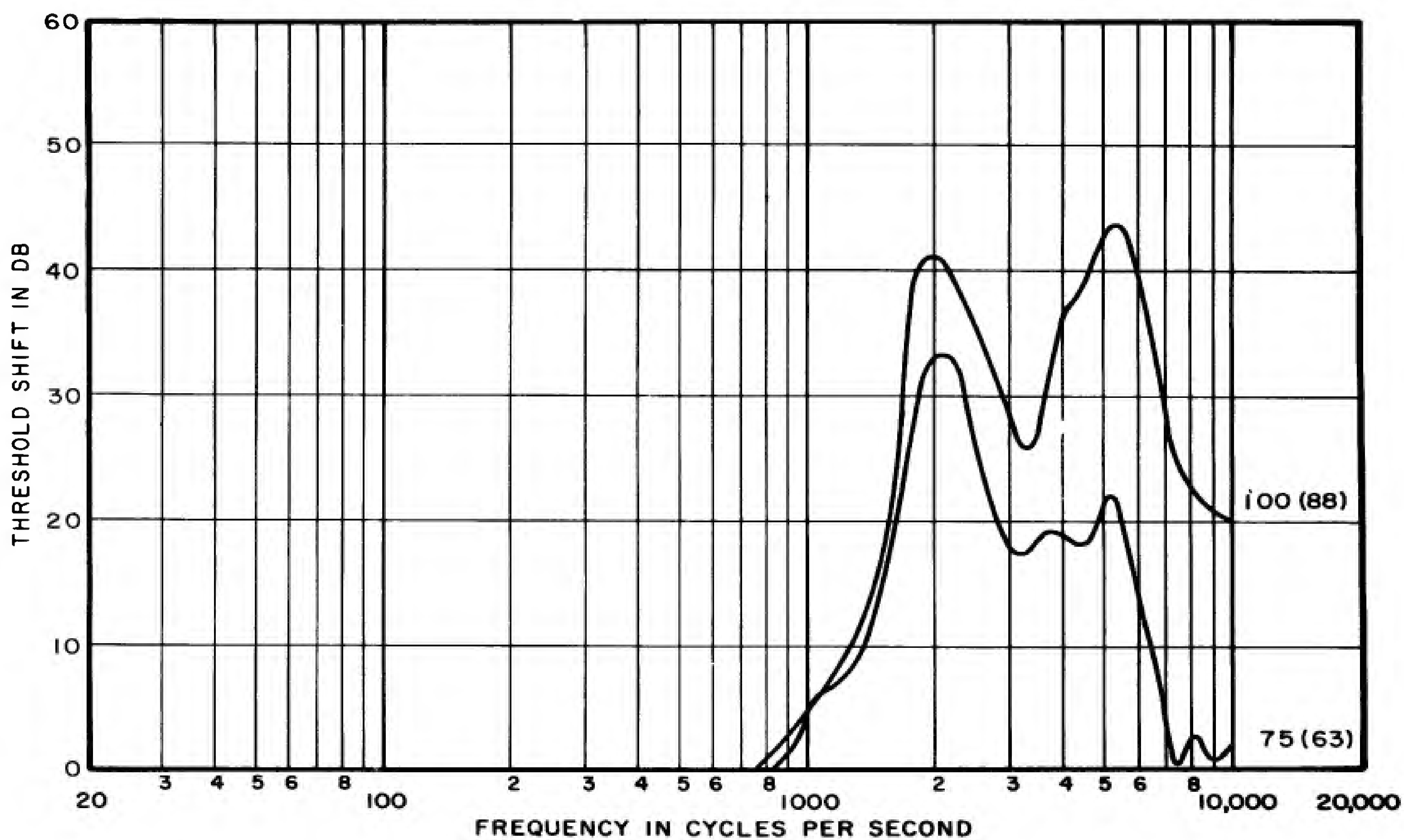

FIG. 9 THRESHOLD SHIFT DUE TO A 2000 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE. SENSATION LEVEL IS IN PARENTHESES.

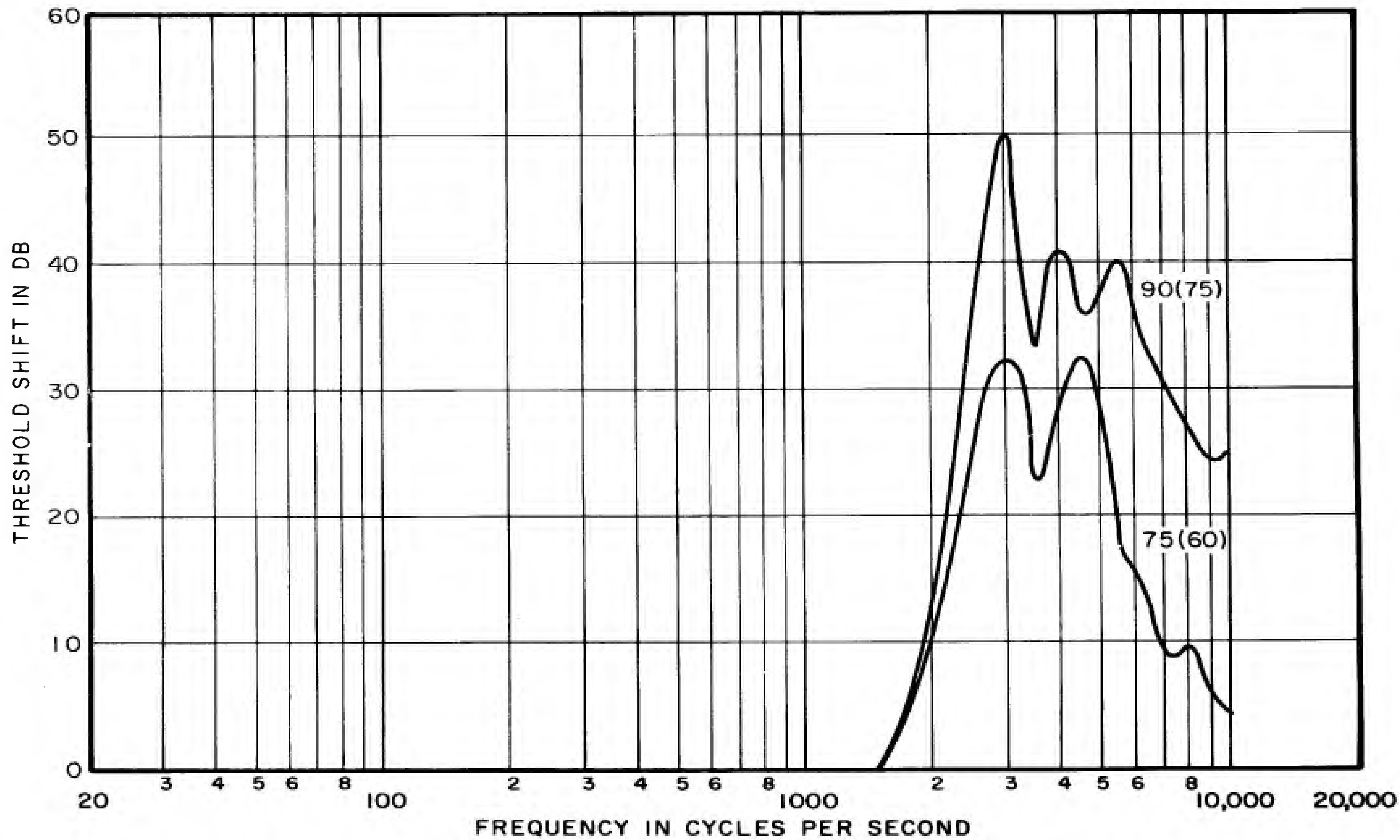

FIG. 10 THRESHOLD SHIFT DUE TO A 3000 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE. SENSATION LEVEL IS IN PARENTHESES.

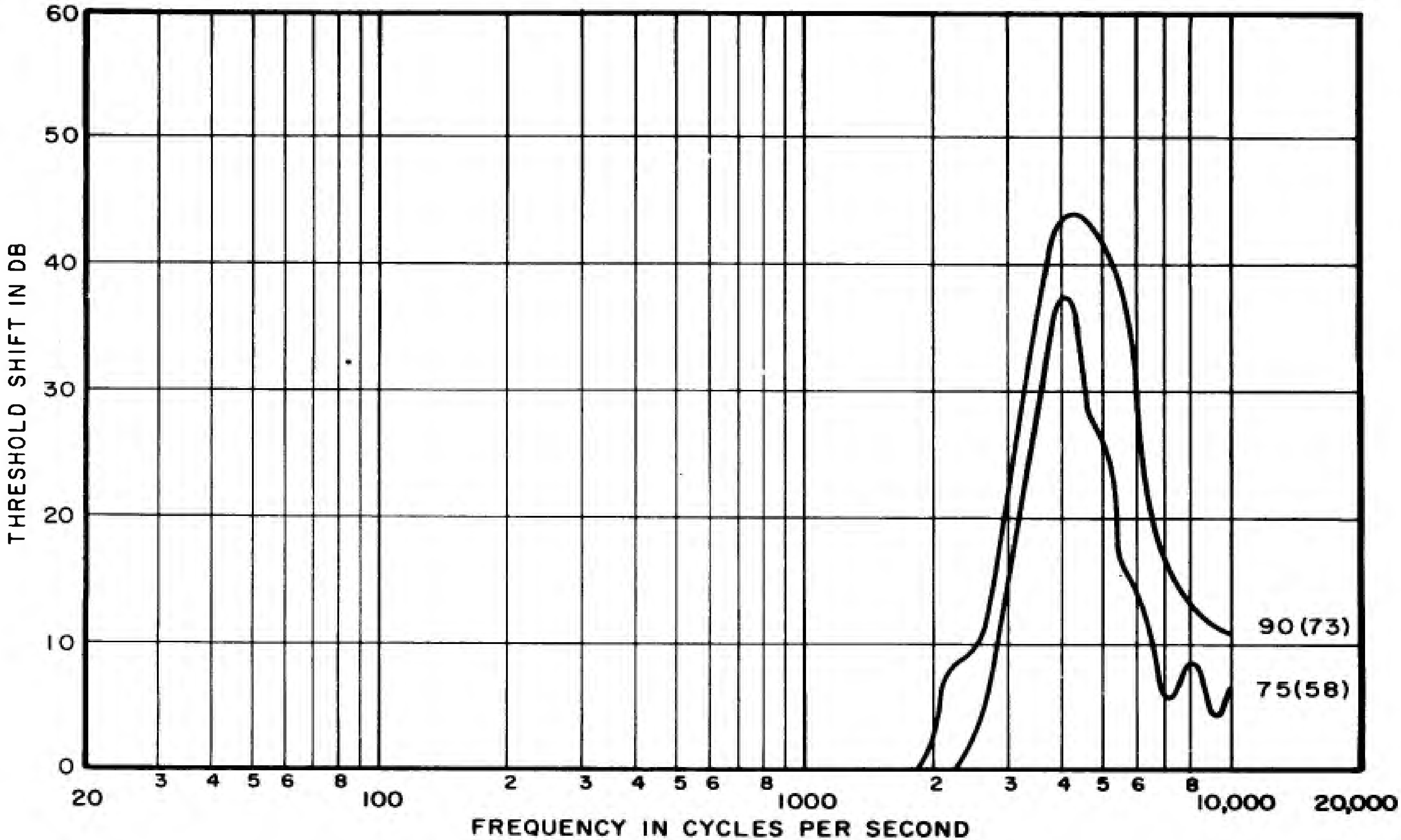

FIG. 11 THRESHOLD SHIFT DUE TO 4000 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE. SENSATION LEVEL IS IN PARENTHESES.

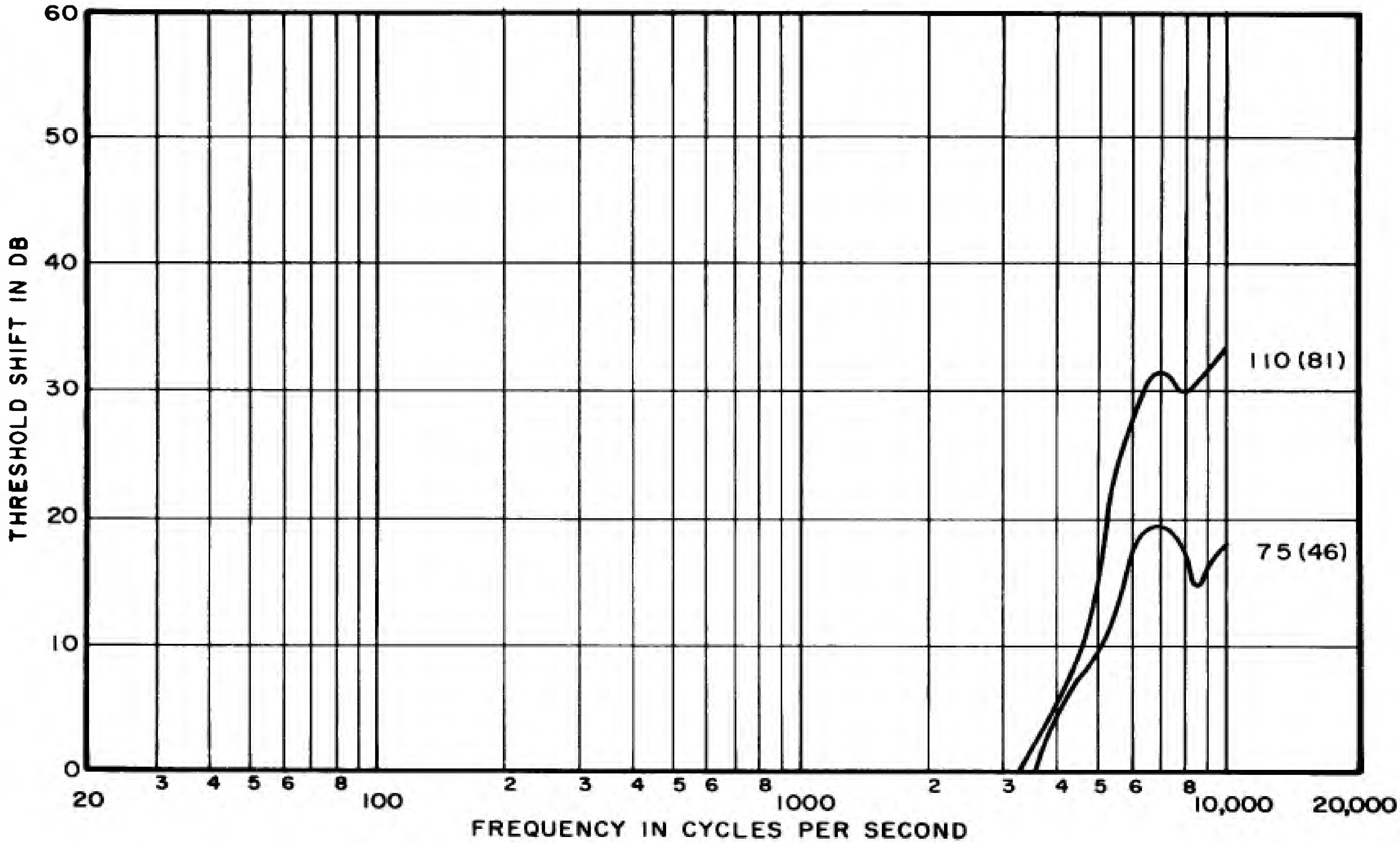

FIG. 12 THRESHOLD SHIFT FROM AN 8000 CPS MASKING TONE. PARAMETER IS THE SPL OF THE MASKING TONE. SENSATION LEVEL IS IN PARENTHESES.

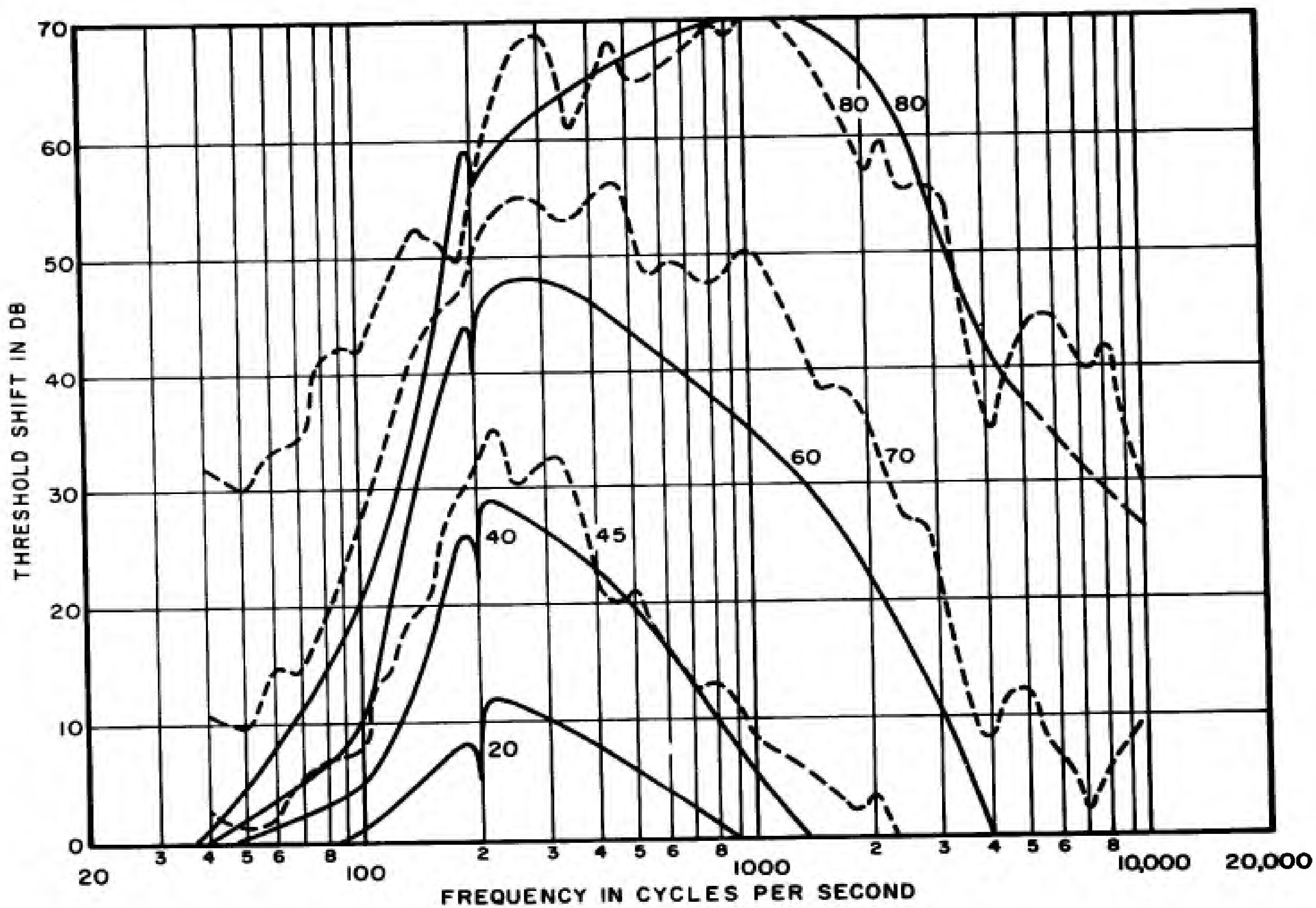

FIG. 13 THRESHOLD SHIFT DUE TO A 200 CPS MASKING TONE. DATA FROM WEGEL & LANE[6] (SOLID CURVES) AND THE PRESENT STUDY (DASHED CURVES). PARAMETER IS THE SENSATION LEVEL OF THE MASKING TONE IN DB.

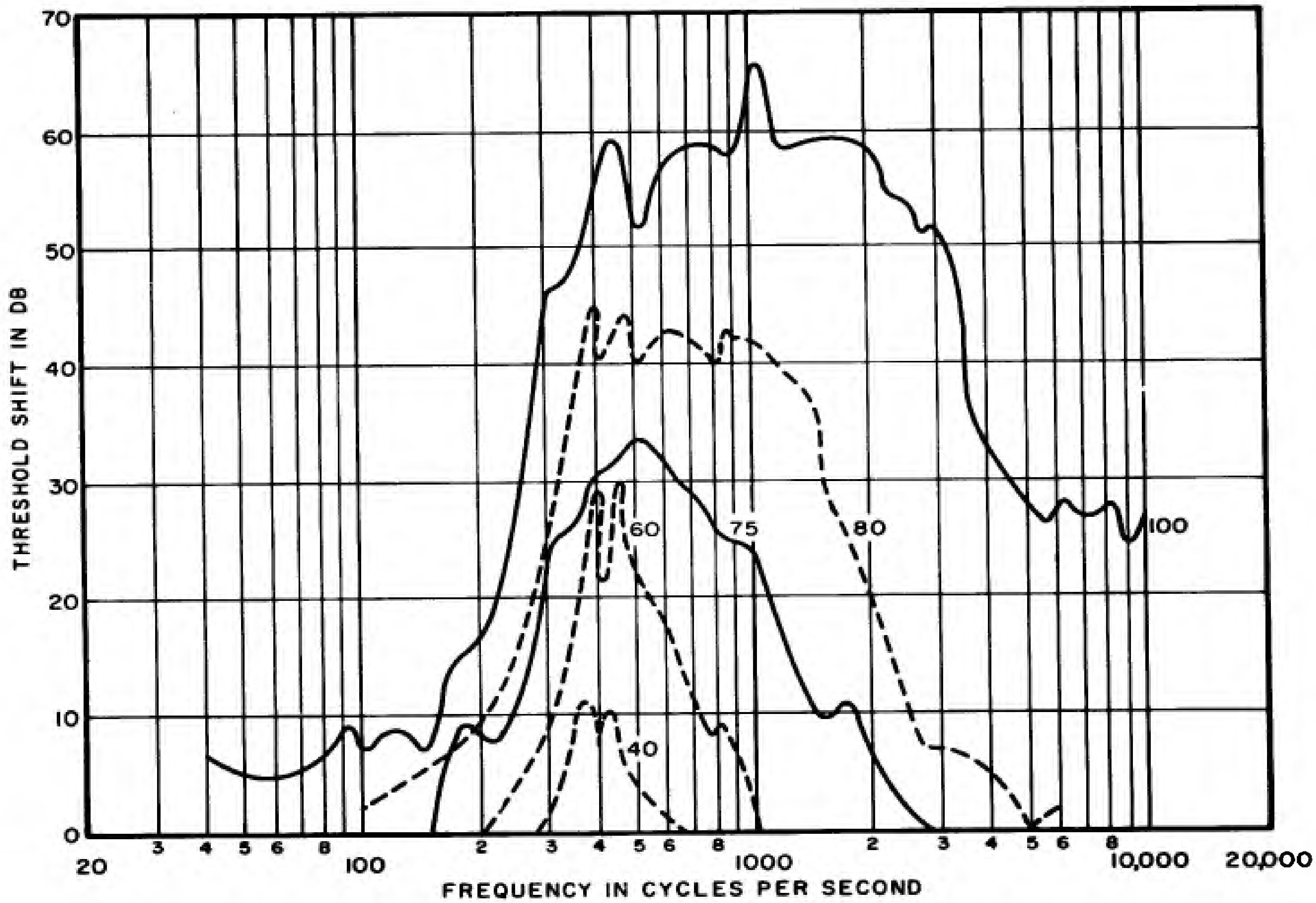

FIG. 14 THRESHOLD SHIFT DUE TO A 400 CPS MASKING TONE. DATA FROM EGAN & HAKE[10] (DASHED CURVES) AND THE PRESENT STUDY (SOLID CURVES). PARAMETER IS THE SPL OF THE MASKING TONE IN DB.

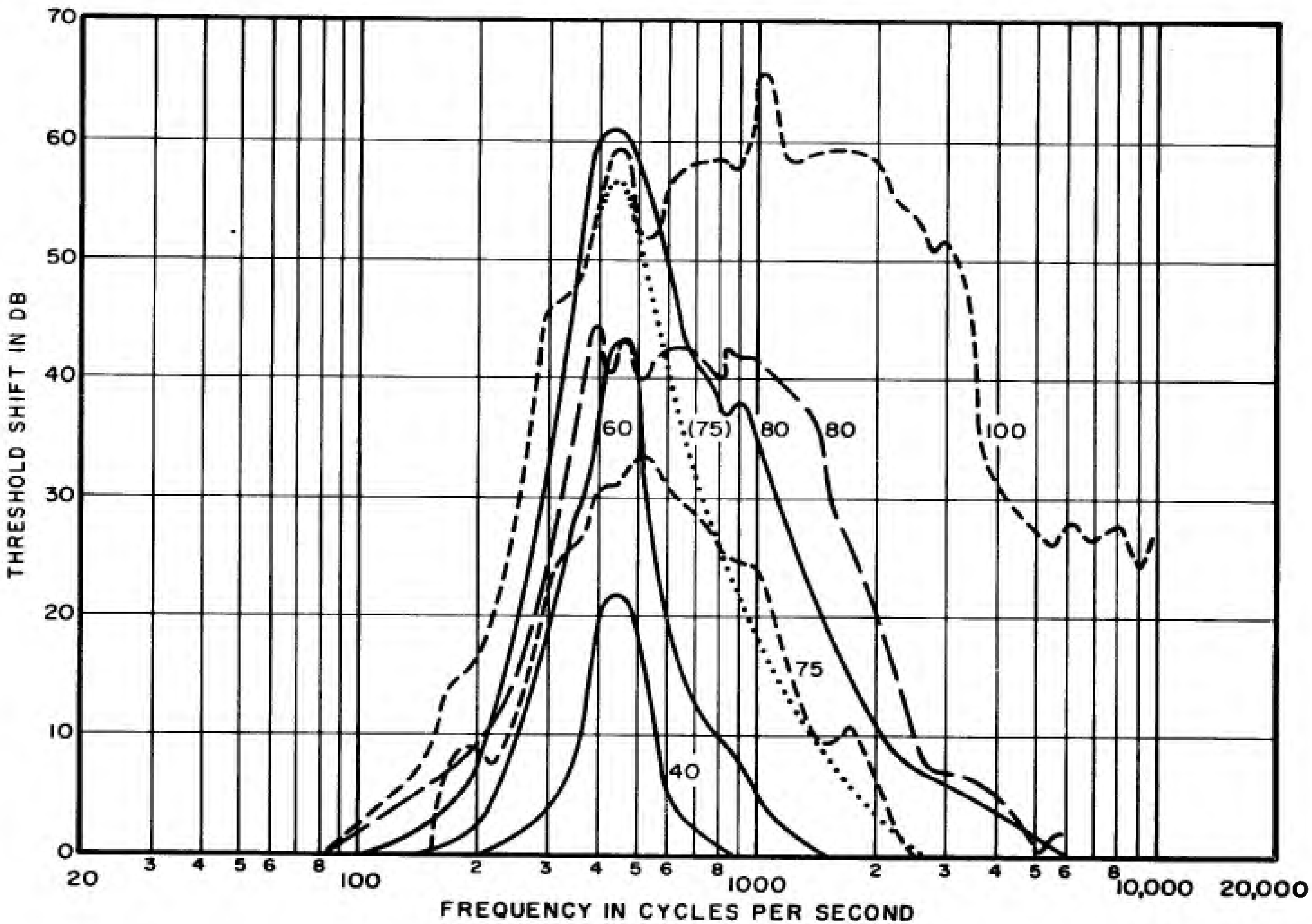

FIG. 15 SOLID CURVES ARE THE MASKING DUE TO A NARROW BAND OF NOISE, 90 CPS WIDE, CENTERED AT 410 CPS (EGAN & HAKE[10]). DASHED CURVES ARE MASKING DUE TO A PURE TONE OF 400 CPS, FROM EGAN & HAKE (LONG DASH) AND THE PRESENT STUDY (SHORT DASH). THE DOTTED CURVE IS VISUALLY INTERPOLATED TO GIVE AN ESTIMATE OF MASKING BY A NARROW BAND NOISE AT AN SPL OF 75 DB.

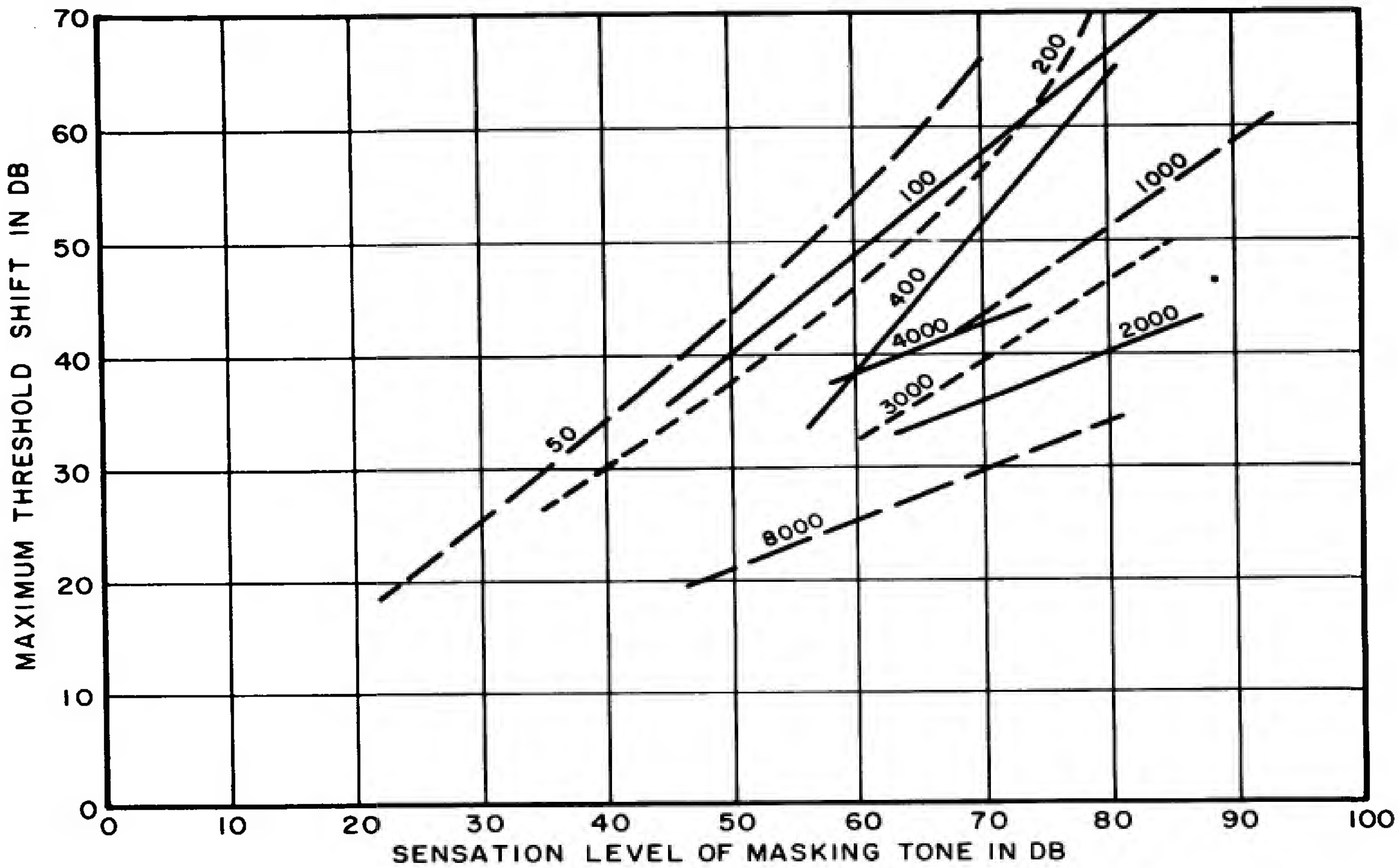

FIG. 16 MAXIMUM THRESHOLD SHIFT AT ANY fs AS A FUNCTION OF SENSATION LEVEL OF THE MASKING TONE. THE PARAMETER IS FREQUENCY IN CPS OF THE MASKING TONE.

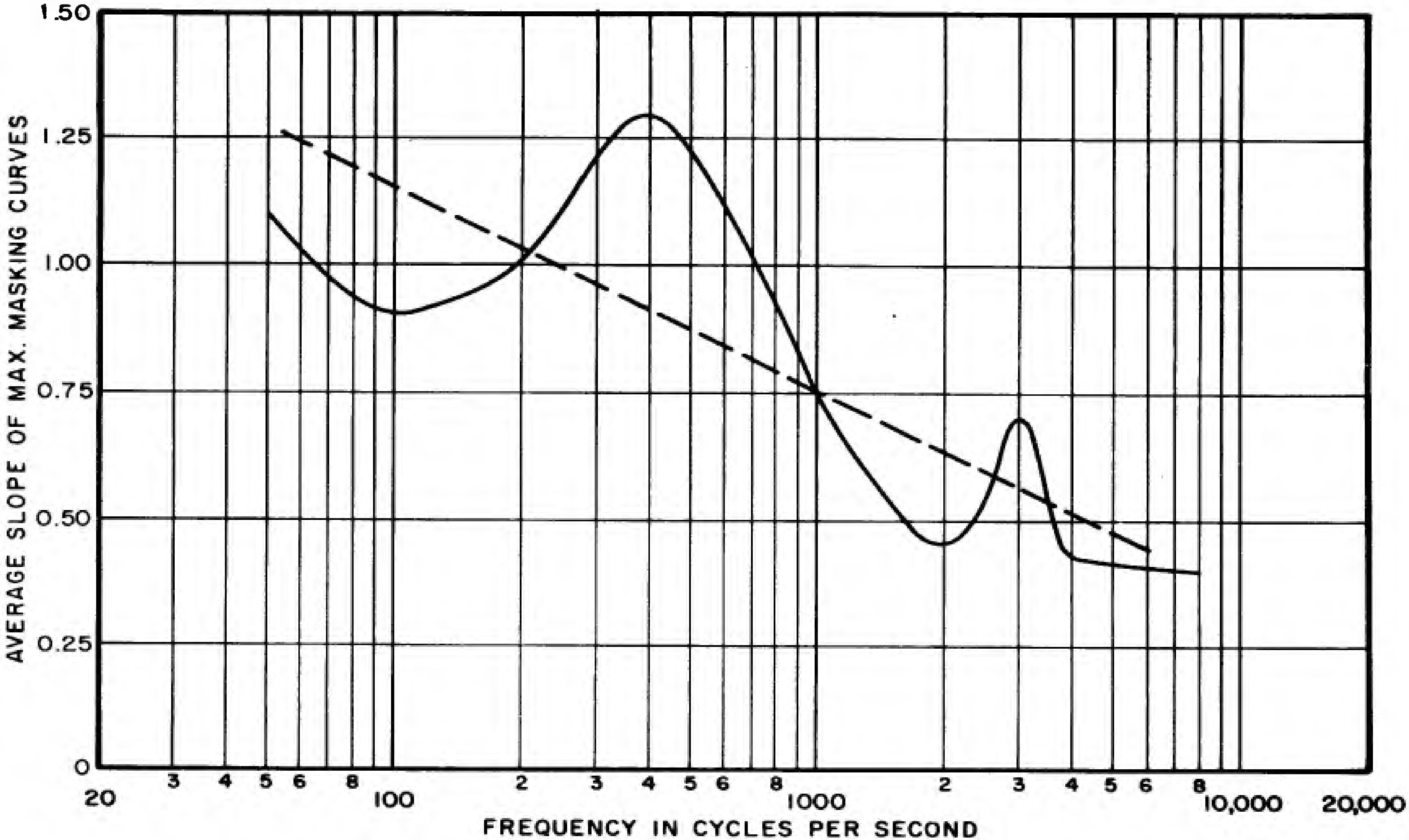

FIG. 17 SLOPE OF THE CURVES OF MAXIMUM MASKING (FIG. 16) AS A FUNCTION OF THE FREQUENCY OF THE MASKING TONE.

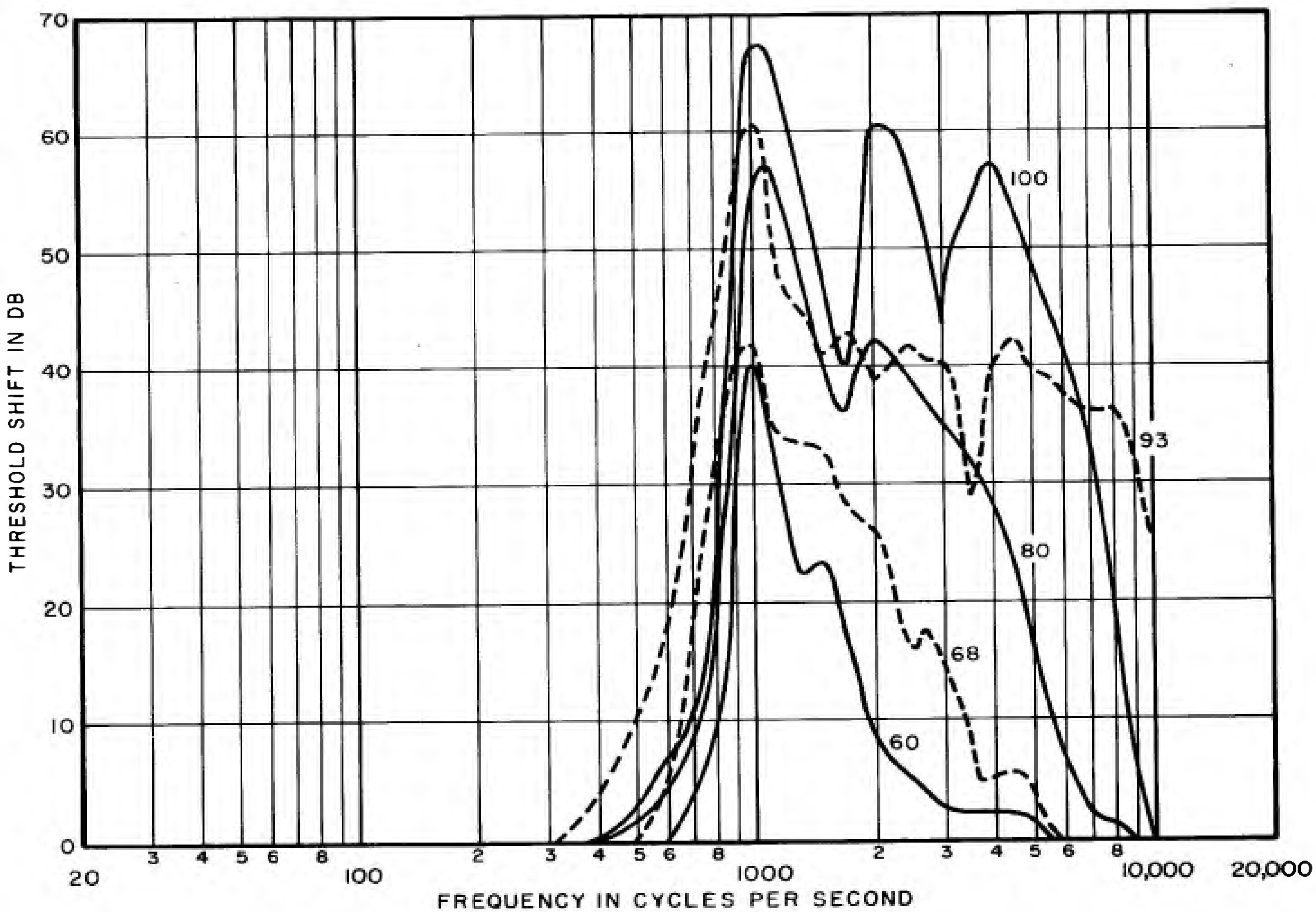

FIG. 18 MASKING DUE TO A 1000 CPS MASKING TONE. SOLID CURVES FROM EHMER[8]. DASHED CURVES FROM THE PRESENT STUDY. PARAMETER IS THE SENSATION LEVEL OF THE MASKING TONE IN DB.

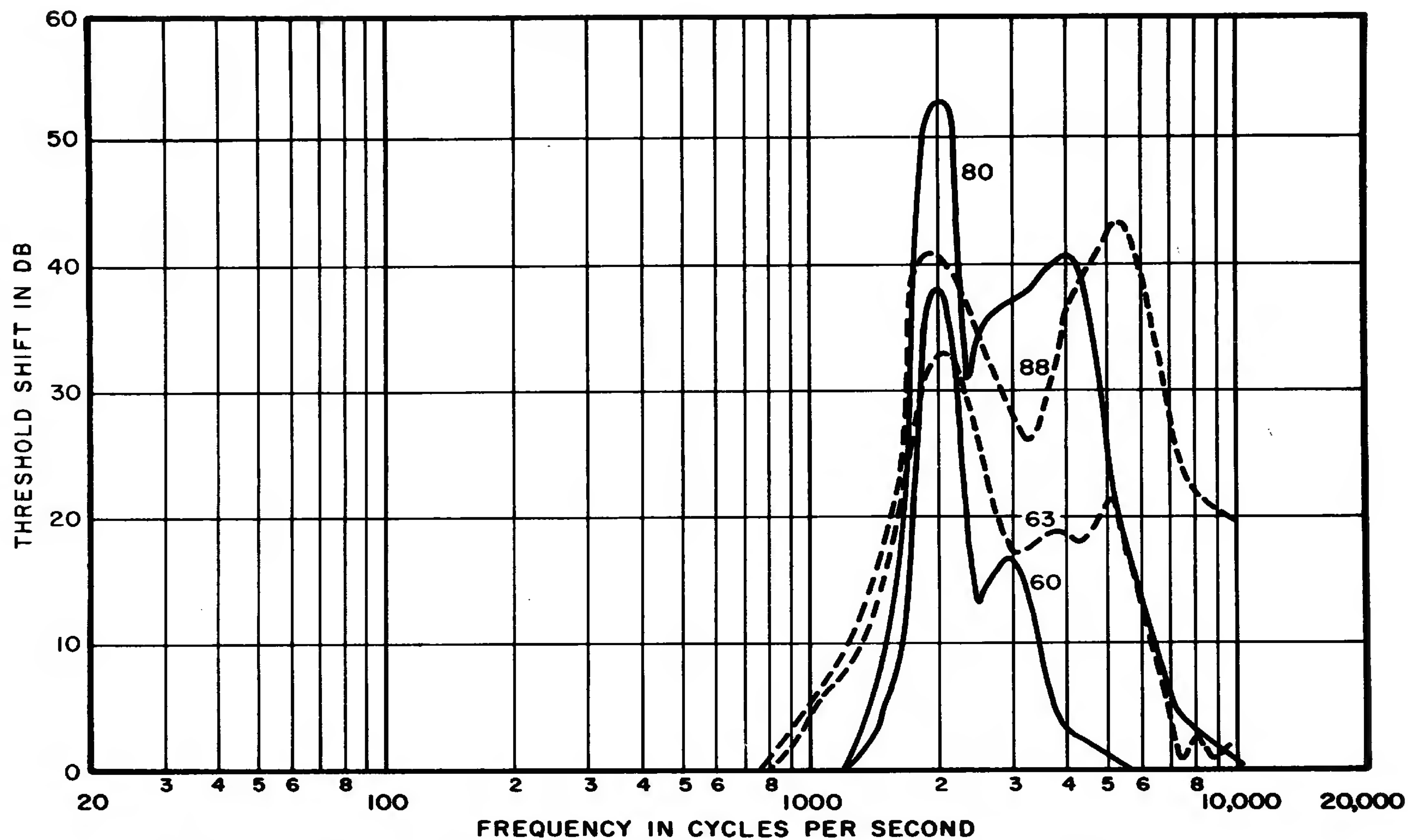

FIG. 19 MASKING DUE TO A 2000 CPS MASKING TONE. SOLID CURVES ARE FROM EHMER; DASHED CURVES FROM THE PRESENT STUDY. PARAMETER IS THE SENSATION LEVEL OF THE MASKING TONE.

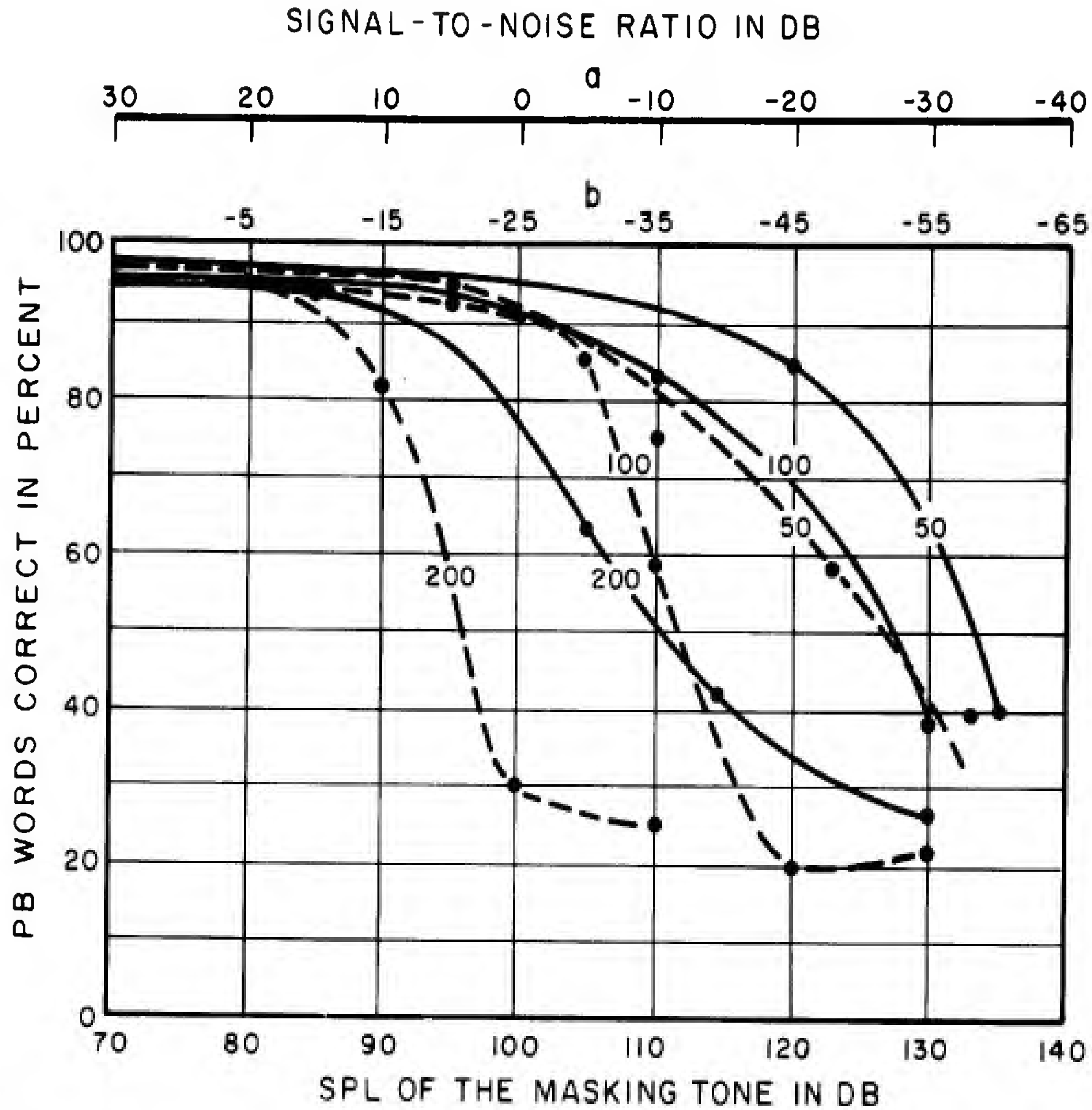

FIG. 20 PERCENT PB WORDS CORRECT AS A FUNCTION OF THE SPL OF THE MASKING TONE. THE SOLID CURVES ARE FOR SPEECH AT AN SPL OF 100 DB. DASHED CURVES ARE FOR SPEECH AT AN SPL OF 75 DB. THE SIGNAL-TO-NOISE RATIOS FOR SPEECH AT 100 DB ARE GIVEN IN THE HORIZONTAL SCALE "a" AT THE TOP OF THE FIGURE; THOSE FOR SPEECH AT 75 DB ARE GIVEN IN SCALE "b".

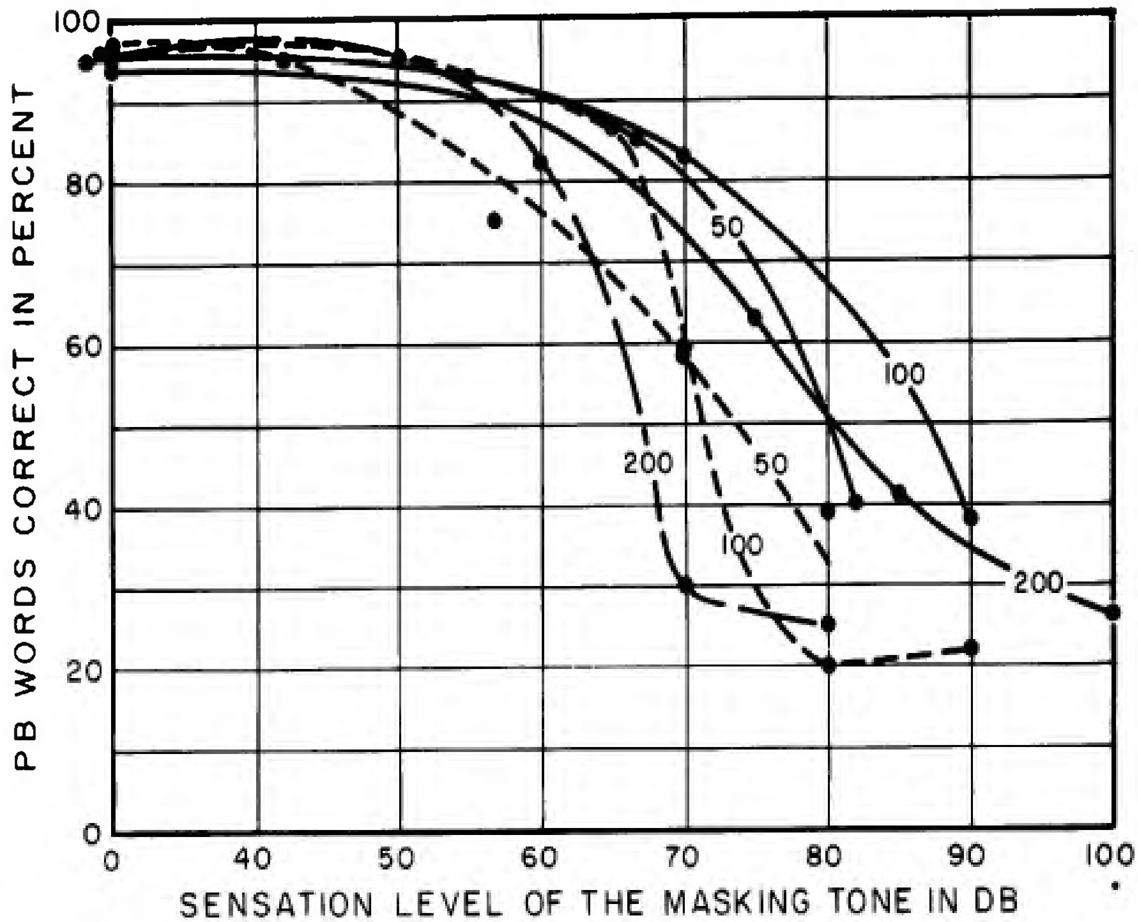

FIG. 21 PERCENT PB WORDS CORRECT AS A FUNCTION OF THE SENSATION LEVEL OF THE MASKING TONE. SOLID CURVES ARE FOR SPEECH AT AN SPL OF 100 DB. DASHED CURVES ARE FOR SPEECH AT AN SPL OF 75 DB. PARAMETER IS FREQUENCY IN CPS OF MASKING TONE.

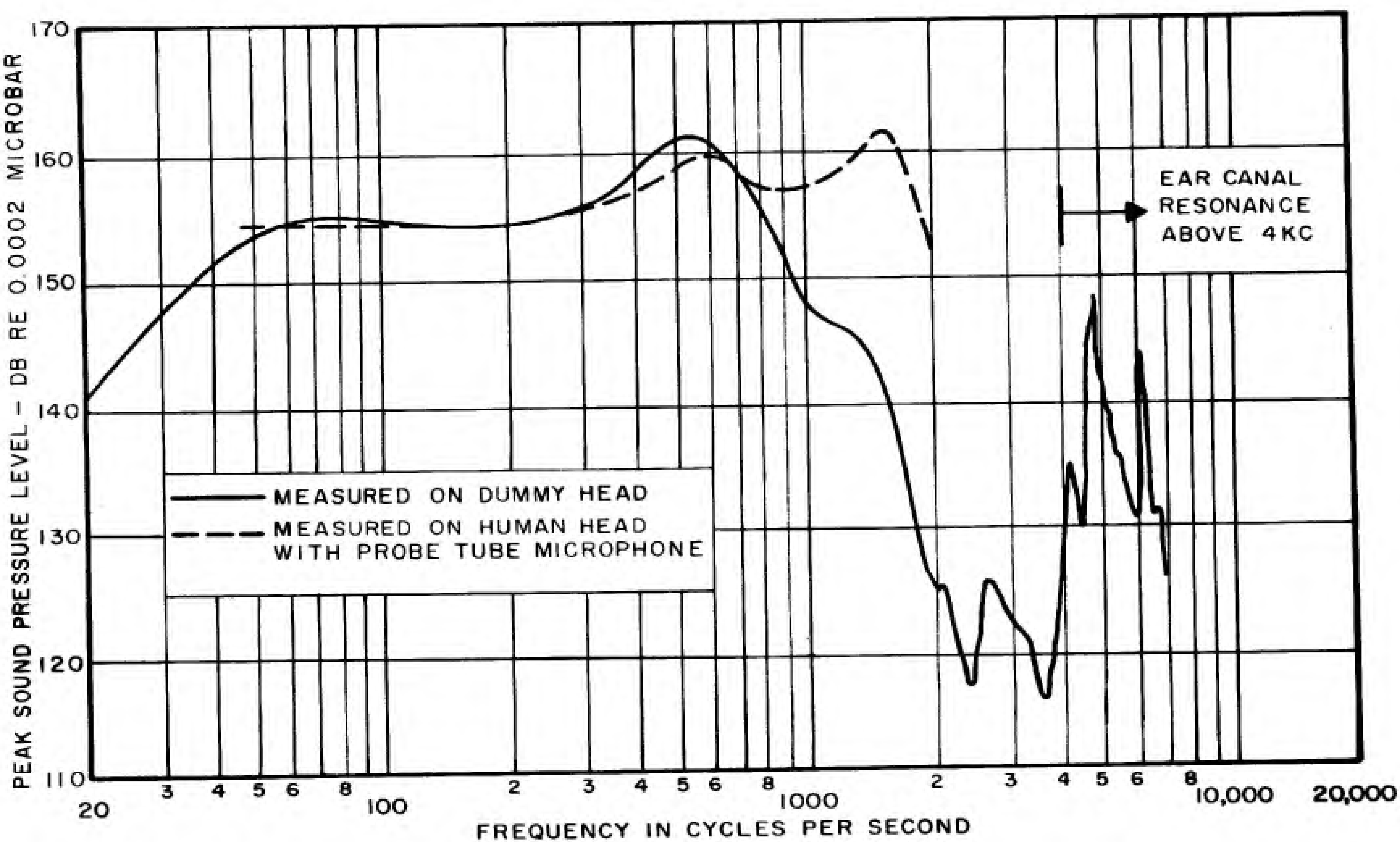

FIG. 22 PURE TONE FREQUENCY RESPONSE OF HIGH-INTENSITY EARPHONE KLH 6.5

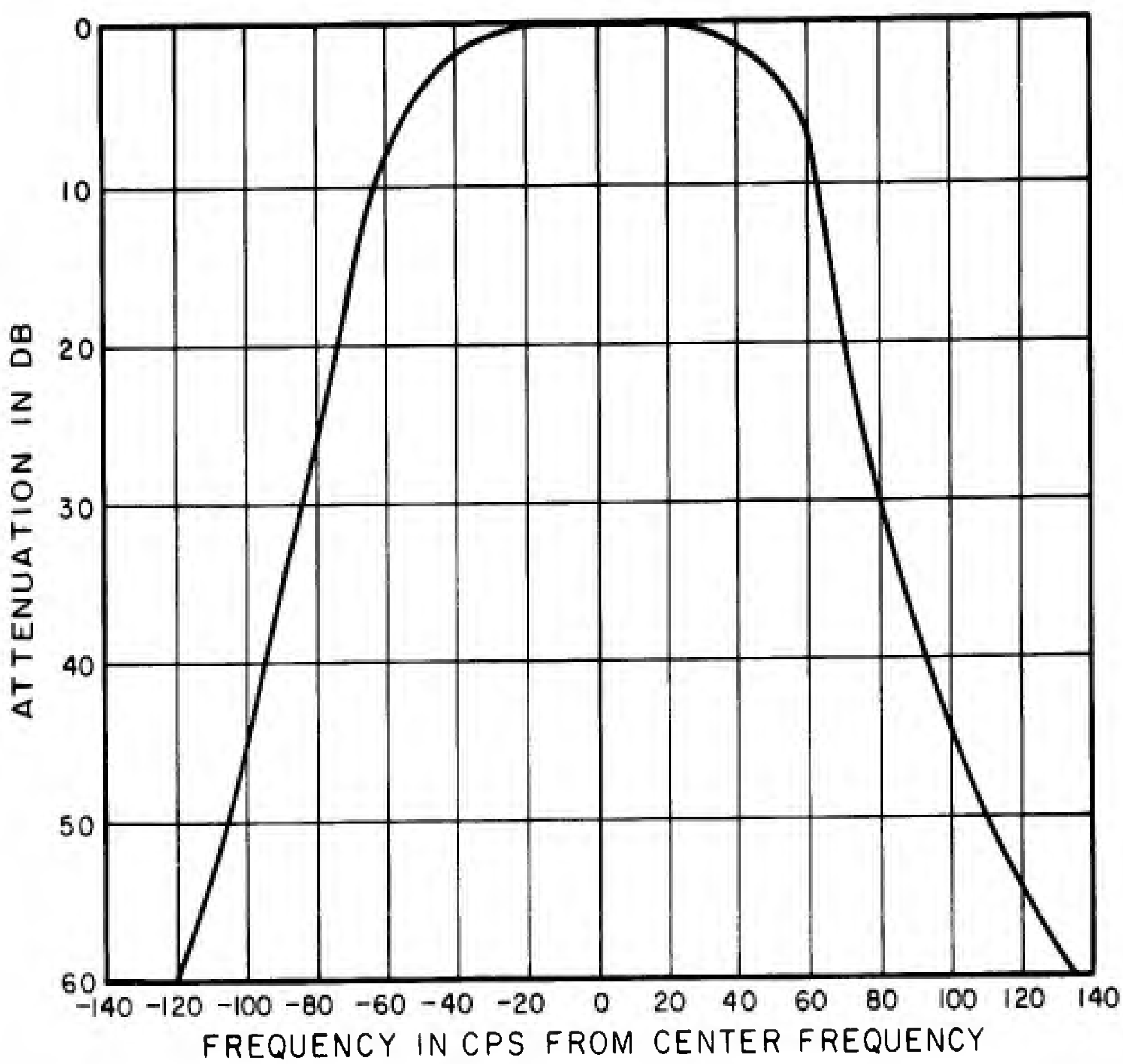

FIG. 23 ATTENUATION CHARACTERISTIC OF THE SUPERHETERODYNE FILTER USED IN RECORDING BANDS OF NOISE 100 CPS WIDE.

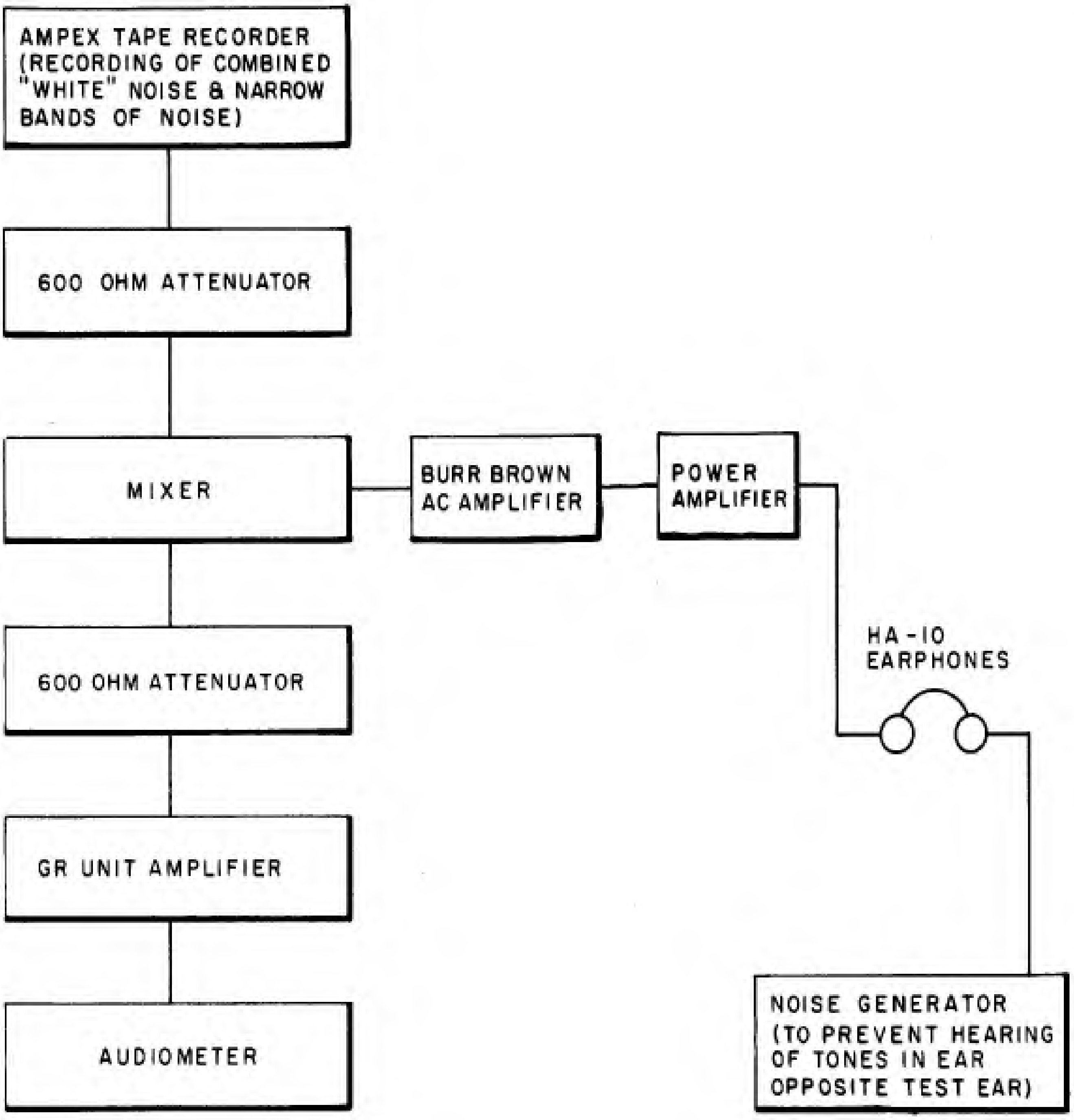

FIG. 24 BLOCK DIAGRAM SHOWING THE ARRANGEMENT OF EQUIPMENT FOR OBTAINING MASKING AUDIOGRAMS IN WHITE NOISE AND NARROW BAND NOISE 100 CPS WIDE

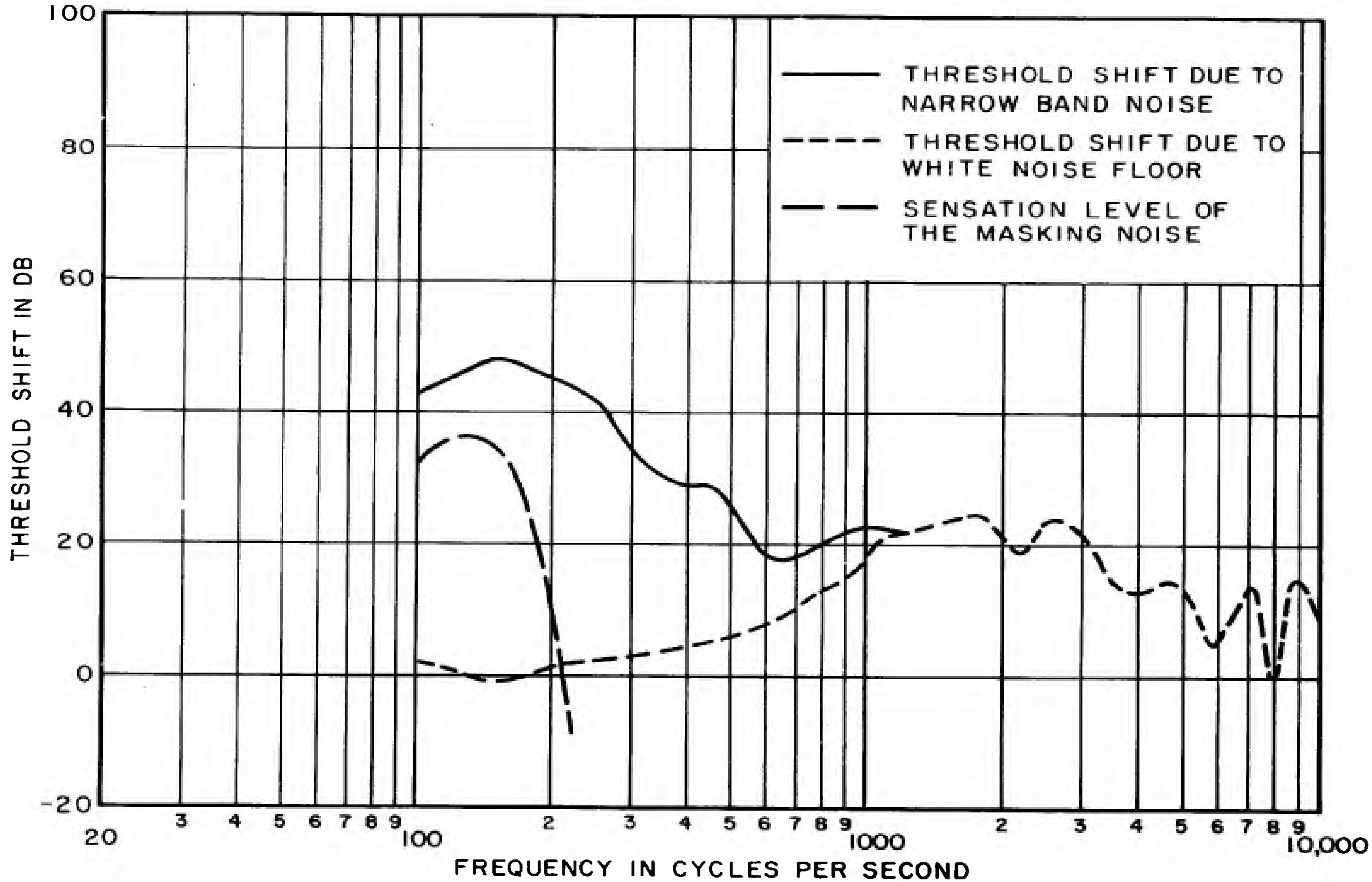

FIG. 25 THRESHOLD SHIFT DUE TO A 75 TO 175 CPS MASKING NOISE AT 90 DB OVERALL SPL.

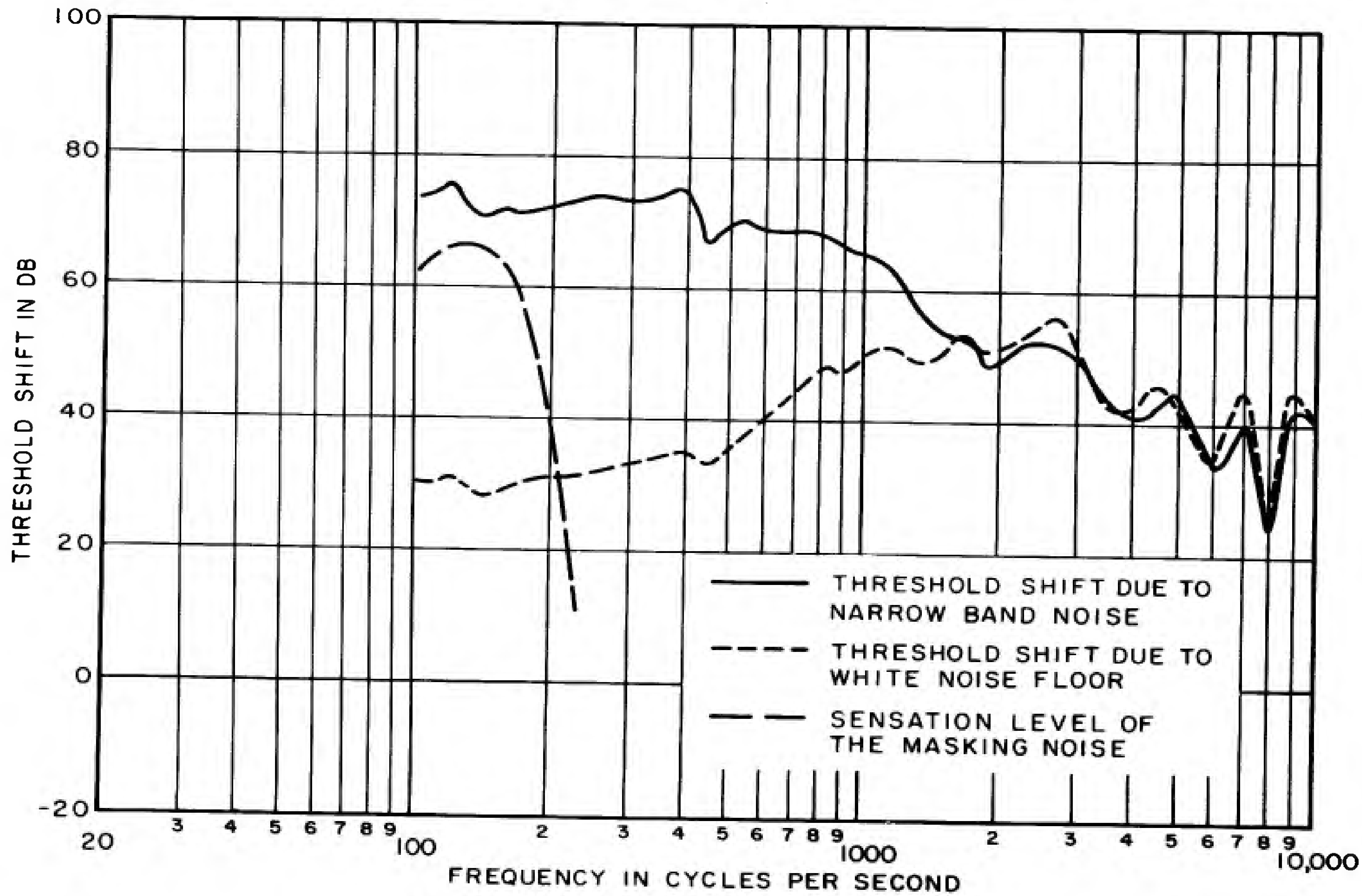

FIG. 26 THRESHOLD SHIFT DUE TO A 75 TO 175 CPS MASKING NOISE AT 120 DB OVERALL SPL.

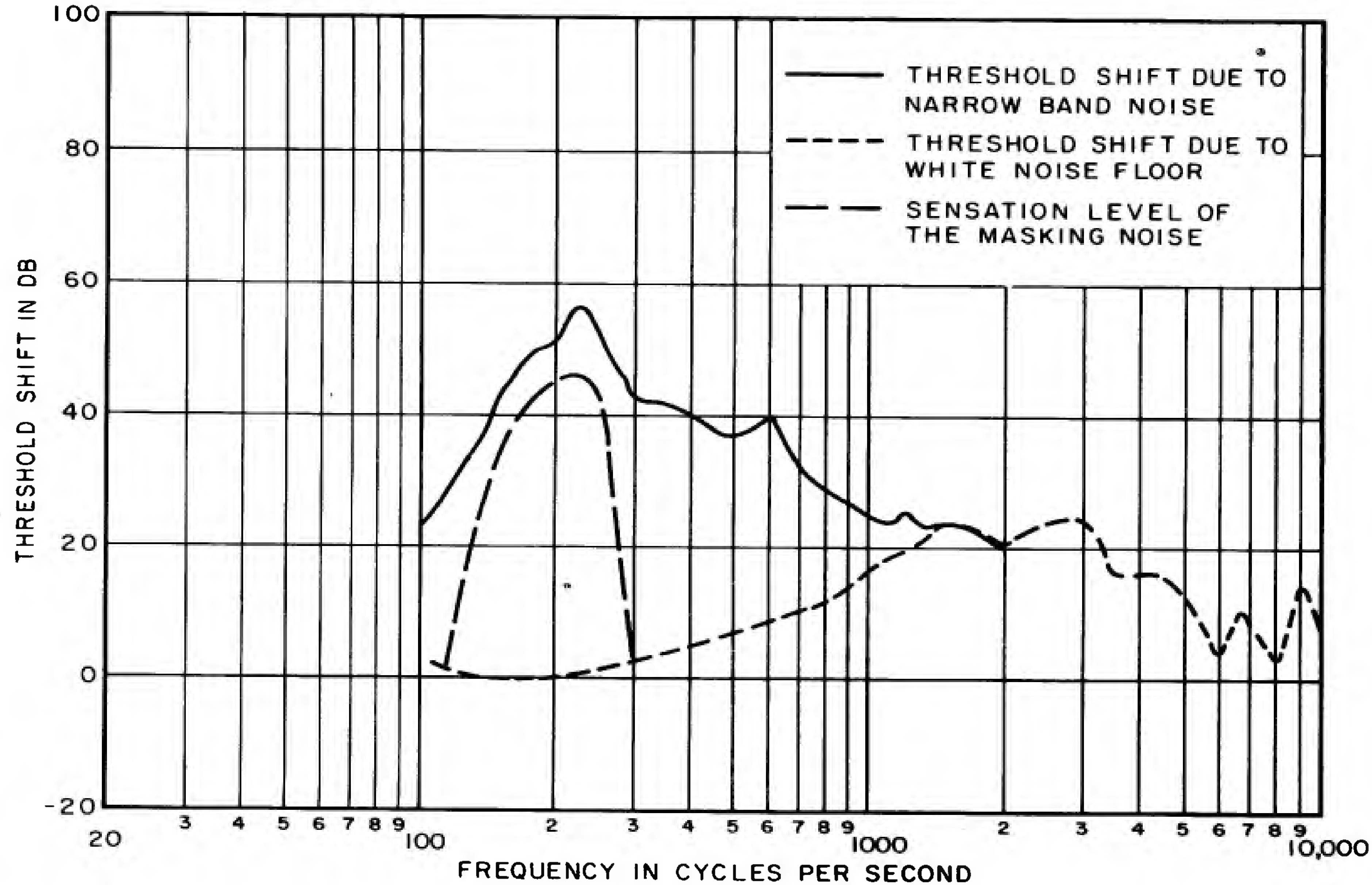

FIG. 27 THRESHOLD SHIFT DUE TO A 150 TO 250 CPS MASKING NOISE AT 90 DB OVERALL SPL.

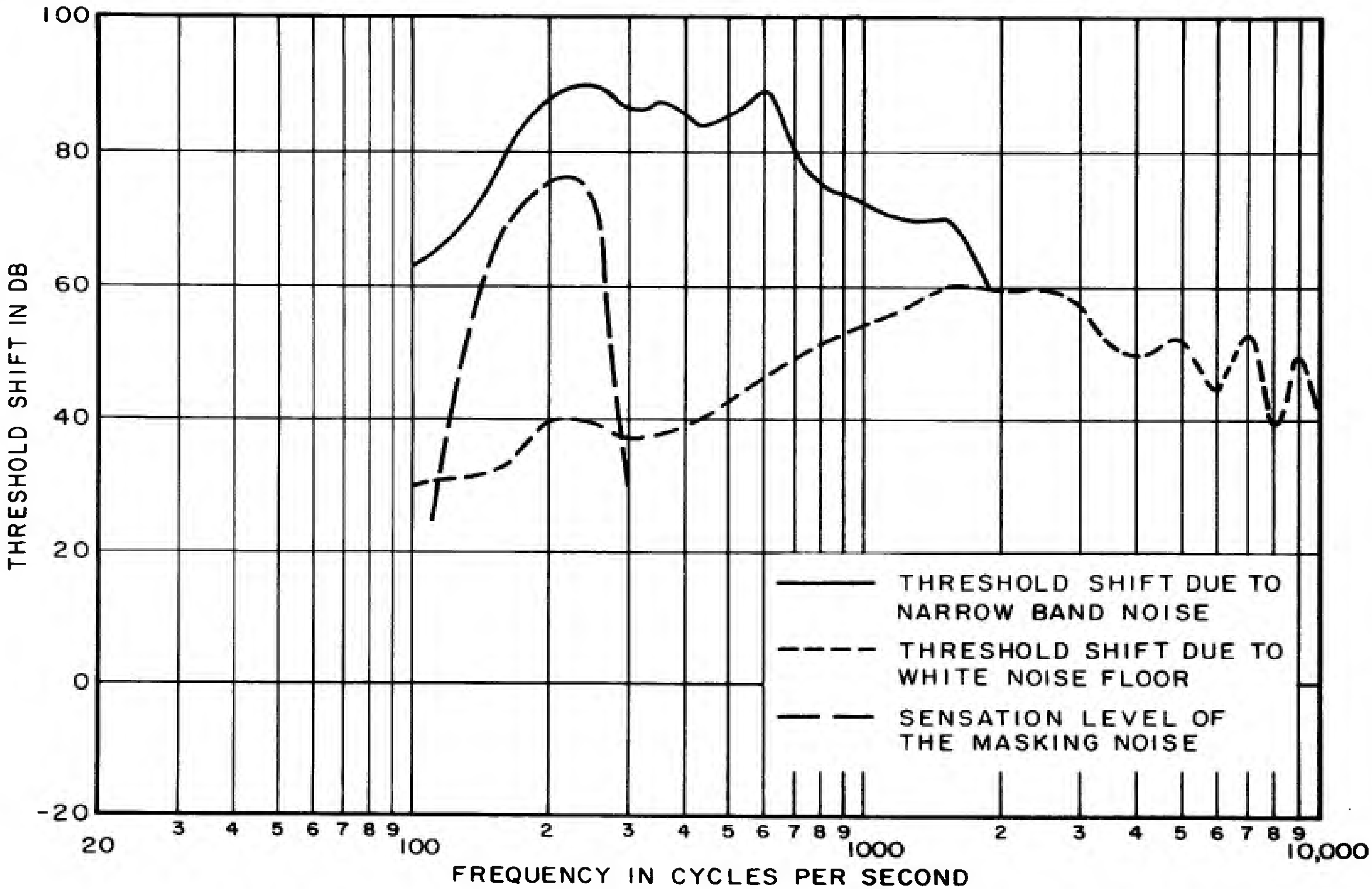

FIG. 28 THRESHOLD SHIFT DUE TO A 150 TO 250 CPS MASKING NOISE AT 120 DB OVERALL SPL.

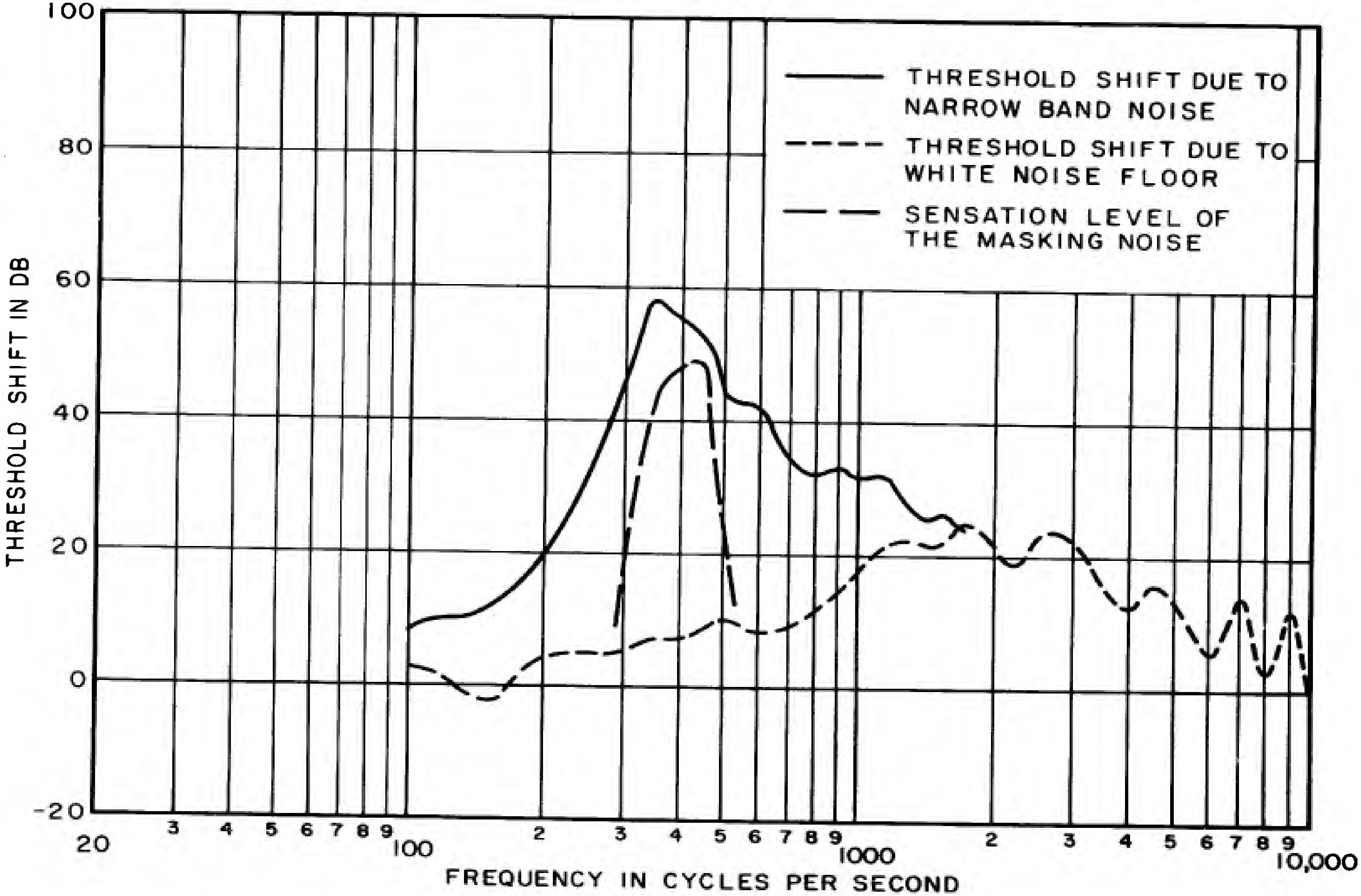

FIG. 29 THRESHOLD SHIFT DUE TO A 350 TO 450 CPS MASKING NOISE AT 85 DB OVERALL SPL.

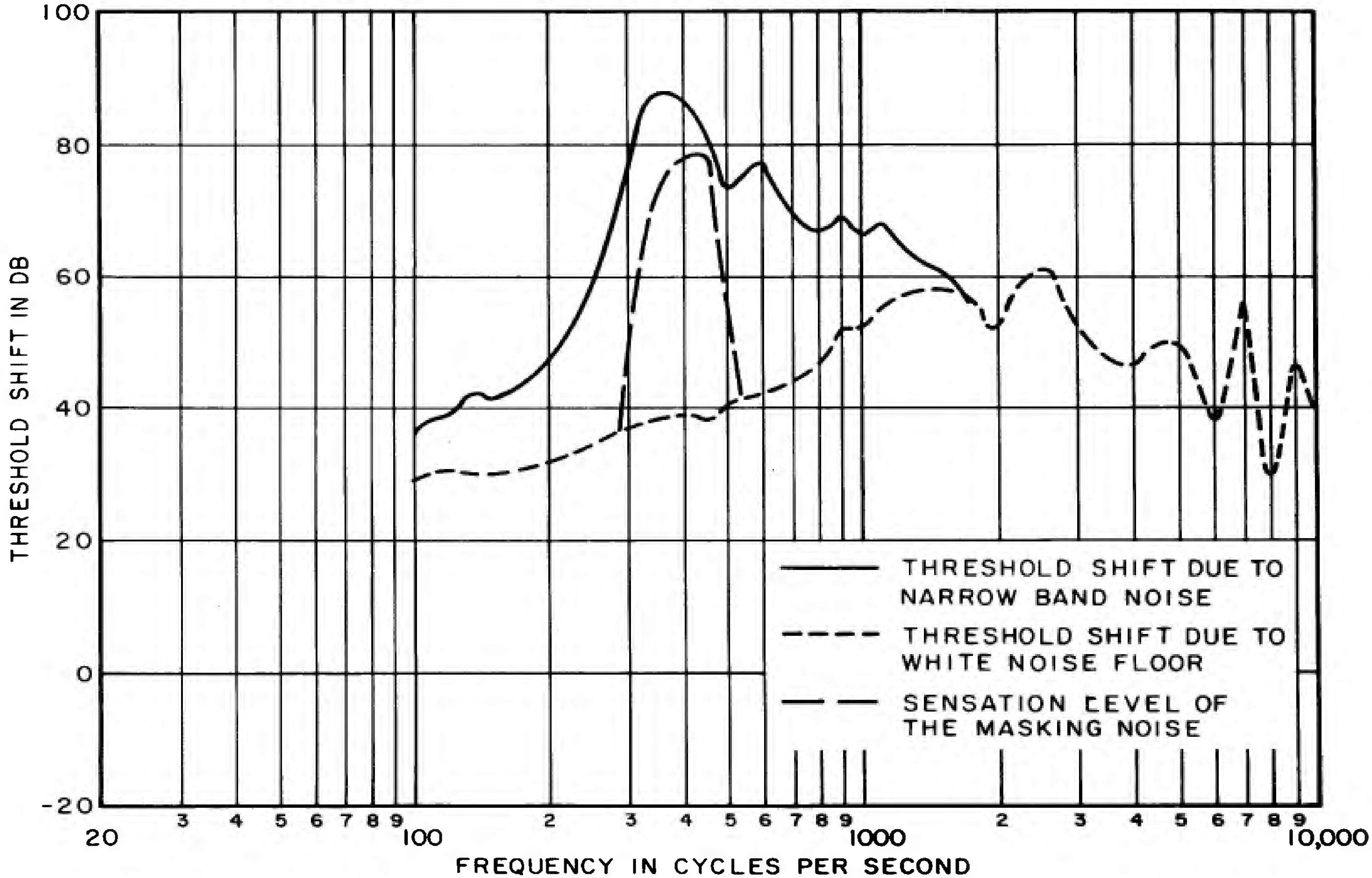

FIG. 30 THRESHOLD SHIFT DUE TO A 350 TO 450 CPS MASKING NOISE AT 115 DB OVERALL SPL.

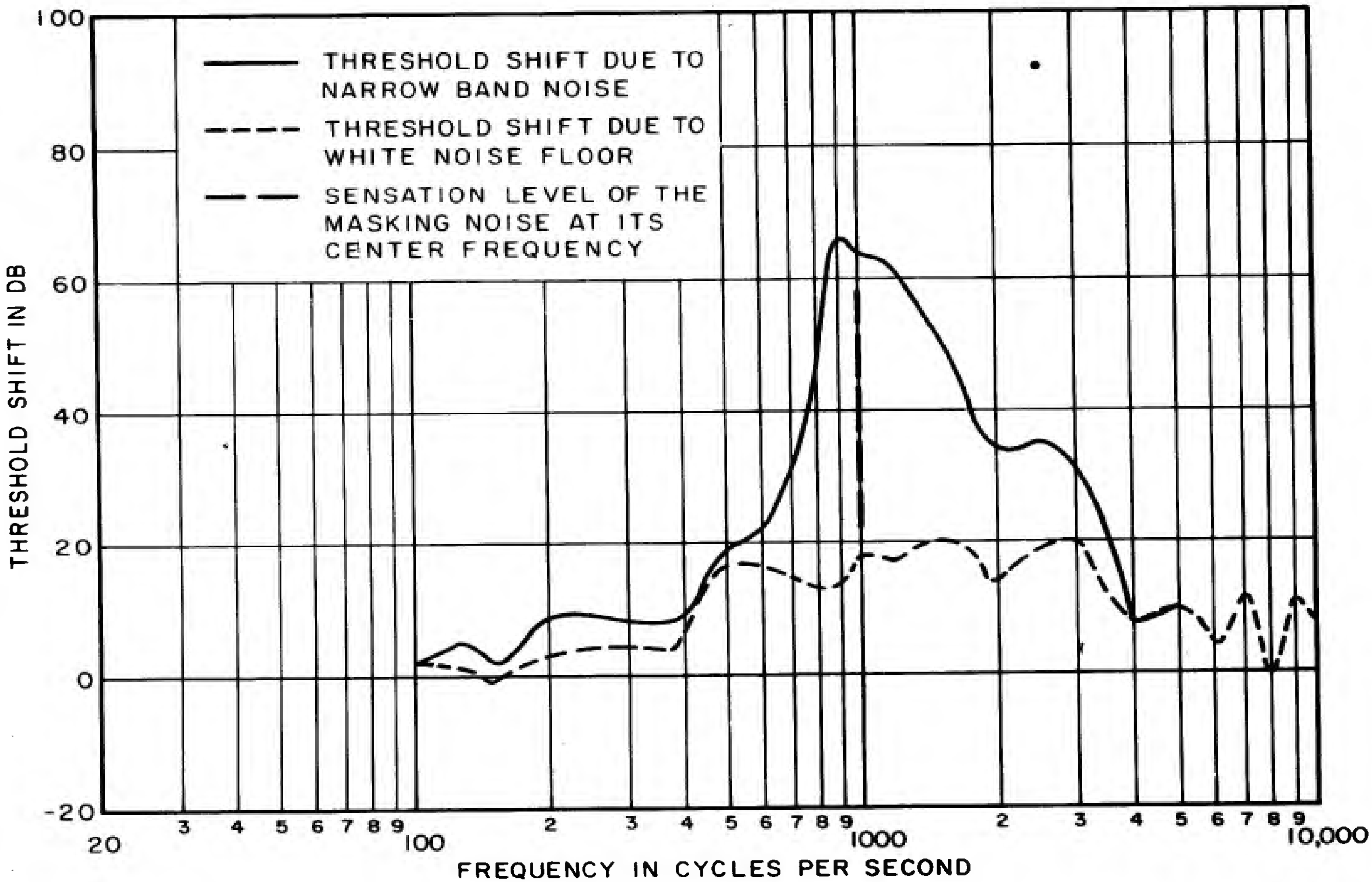

FIG. 31 THRESHOLD SHIFT DUE TO A 950 TO 1050 CPS MASKING NOISE AT 80 DB OVERALL SPL.

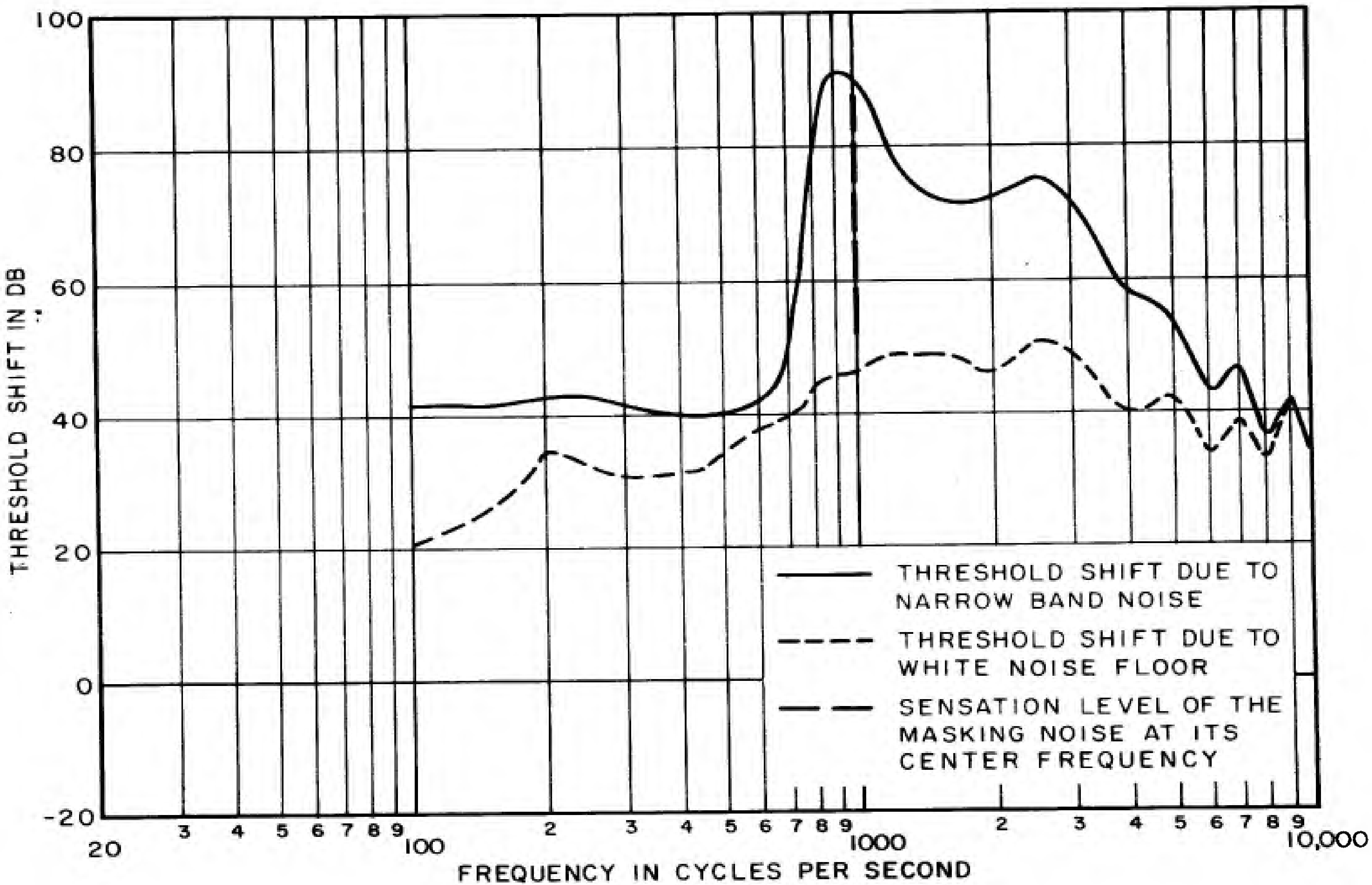

FIG. 32 THRESHOLD SHIFT DUE TO A 950 TO 1050 CPS MASKING NOISE AT 110 DB OVERALL SPL.

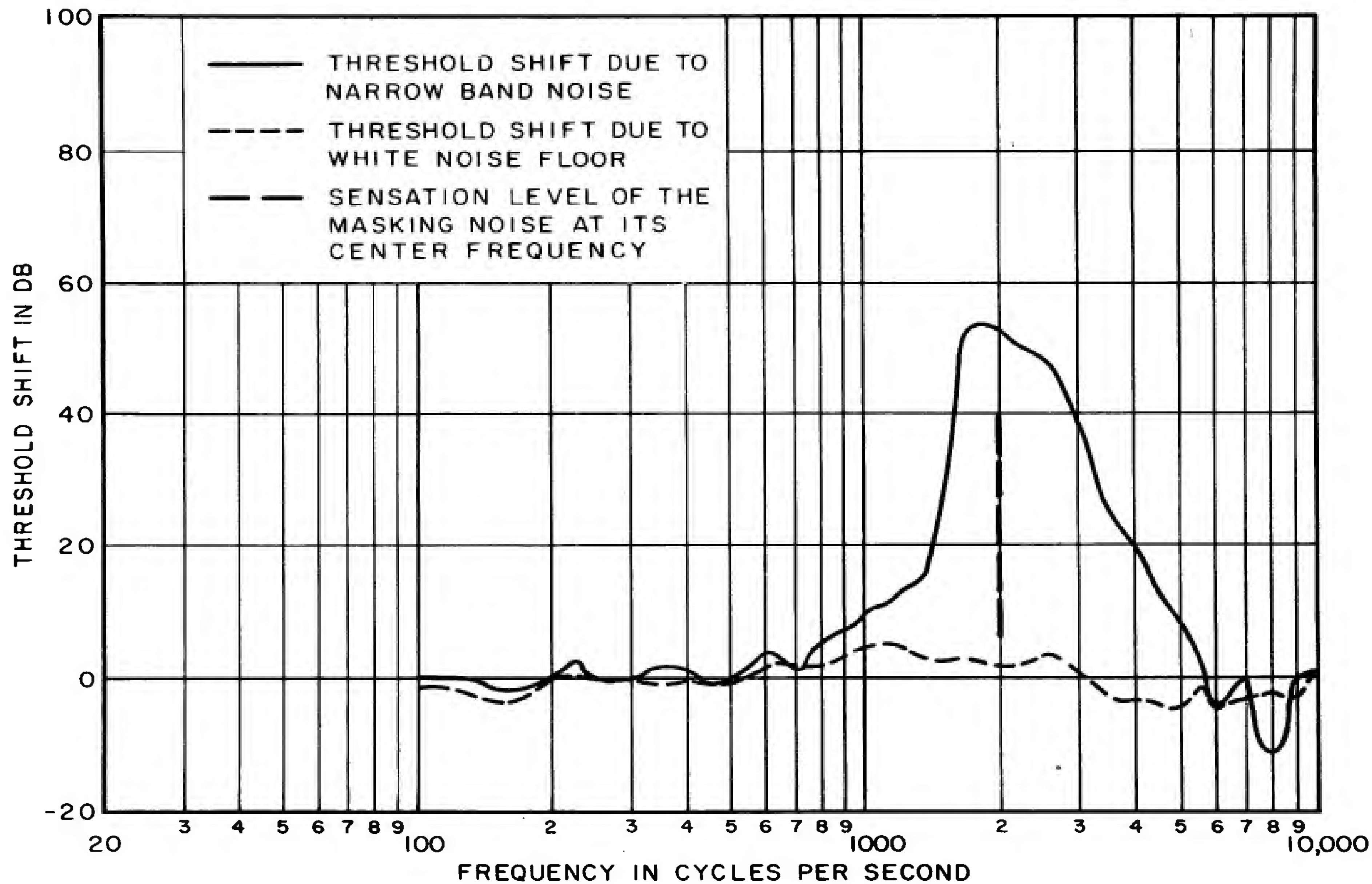

FIG. 33 THRESHOLD SHIFT DUE TO A 1950 TO 2050 CPS MASKING NOISE AT 70 DB OVERALL SPL.

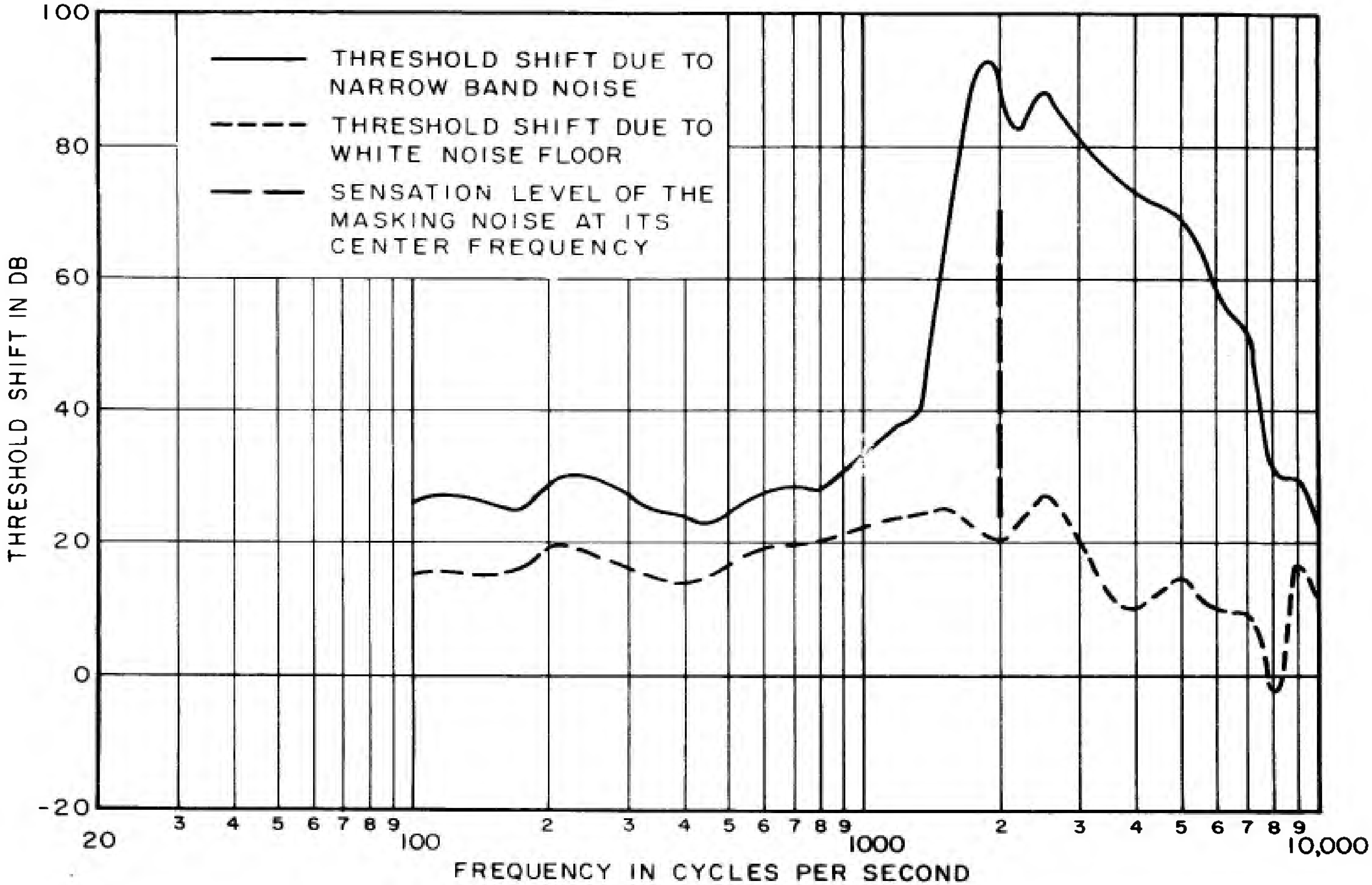

FIG.34 THRESHOLD SHIFT DUE TO A 1950 TO 2050 CPS MASKING NOISE AT 100 DB OVERALL SPL.

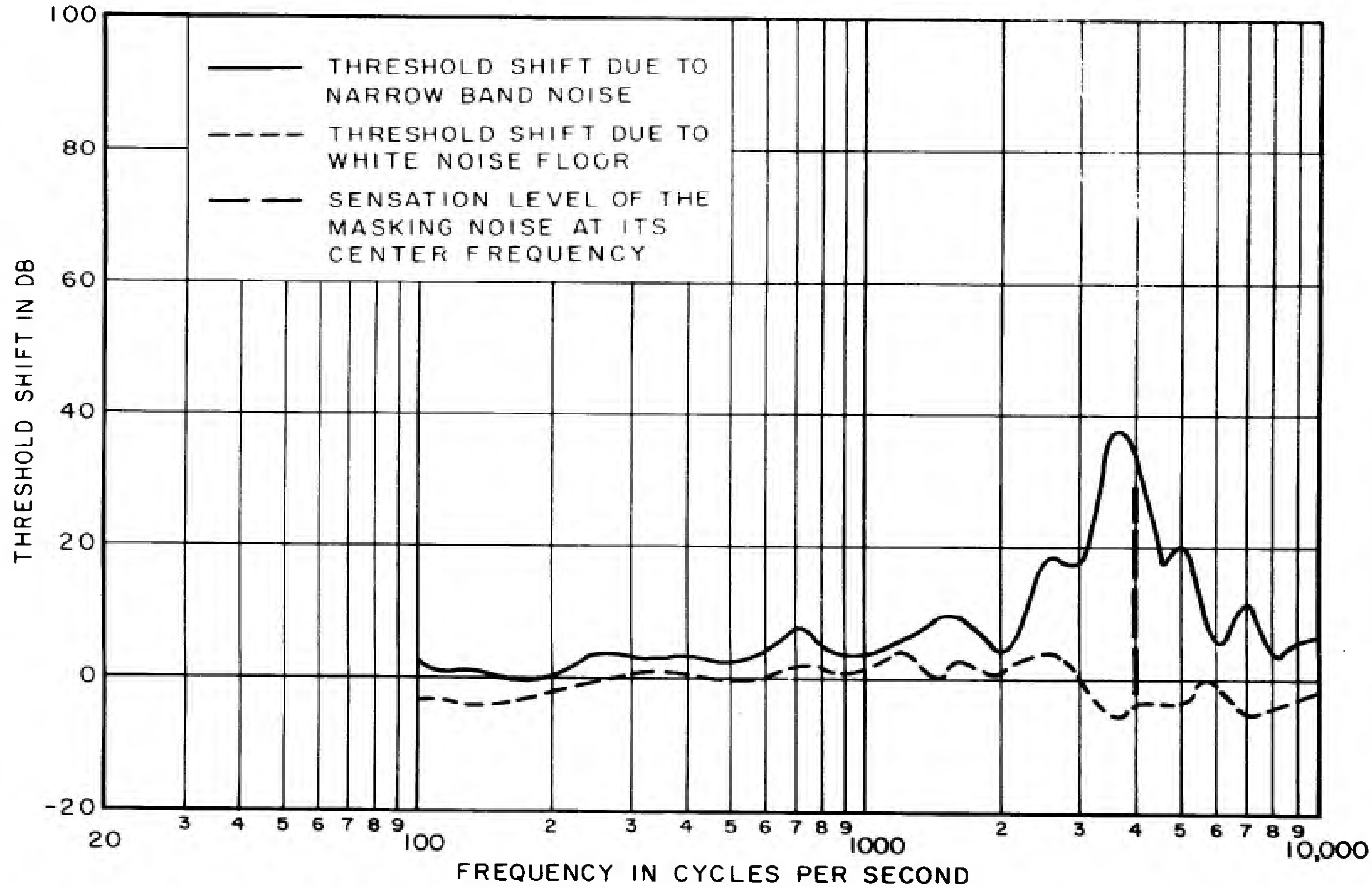

FIG. 35 THRESHOLD SHIFT DUE TO A 3950 TO 4050 CPS MASKING NOISE AT 70 DB OVERALL SPL.

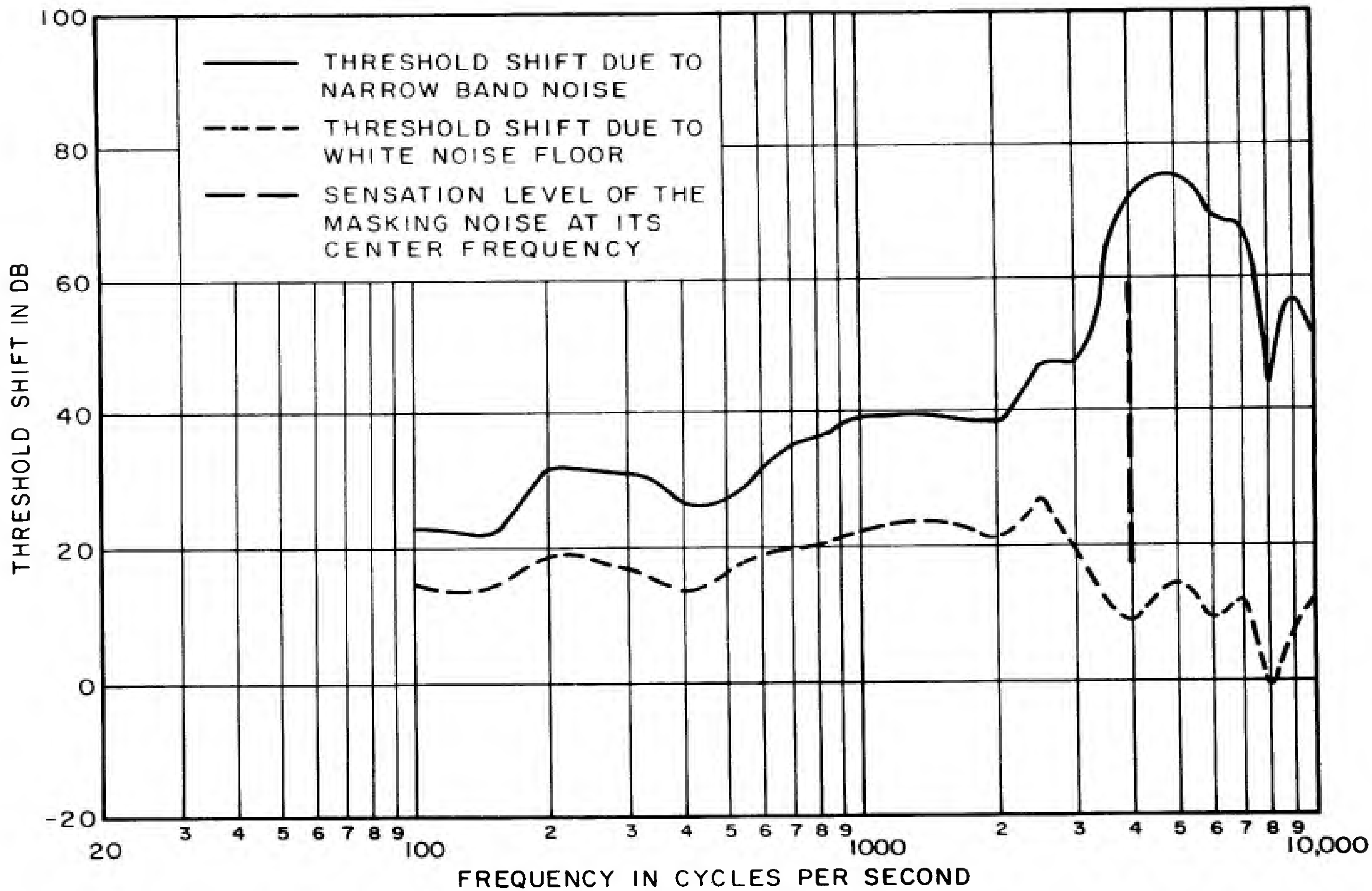

FIG. 36 THRESHOLD SHIFT DUE TO A 3950 TO 4050 CPS MASKING NOISE AT 100 DB OVERALL SPL.

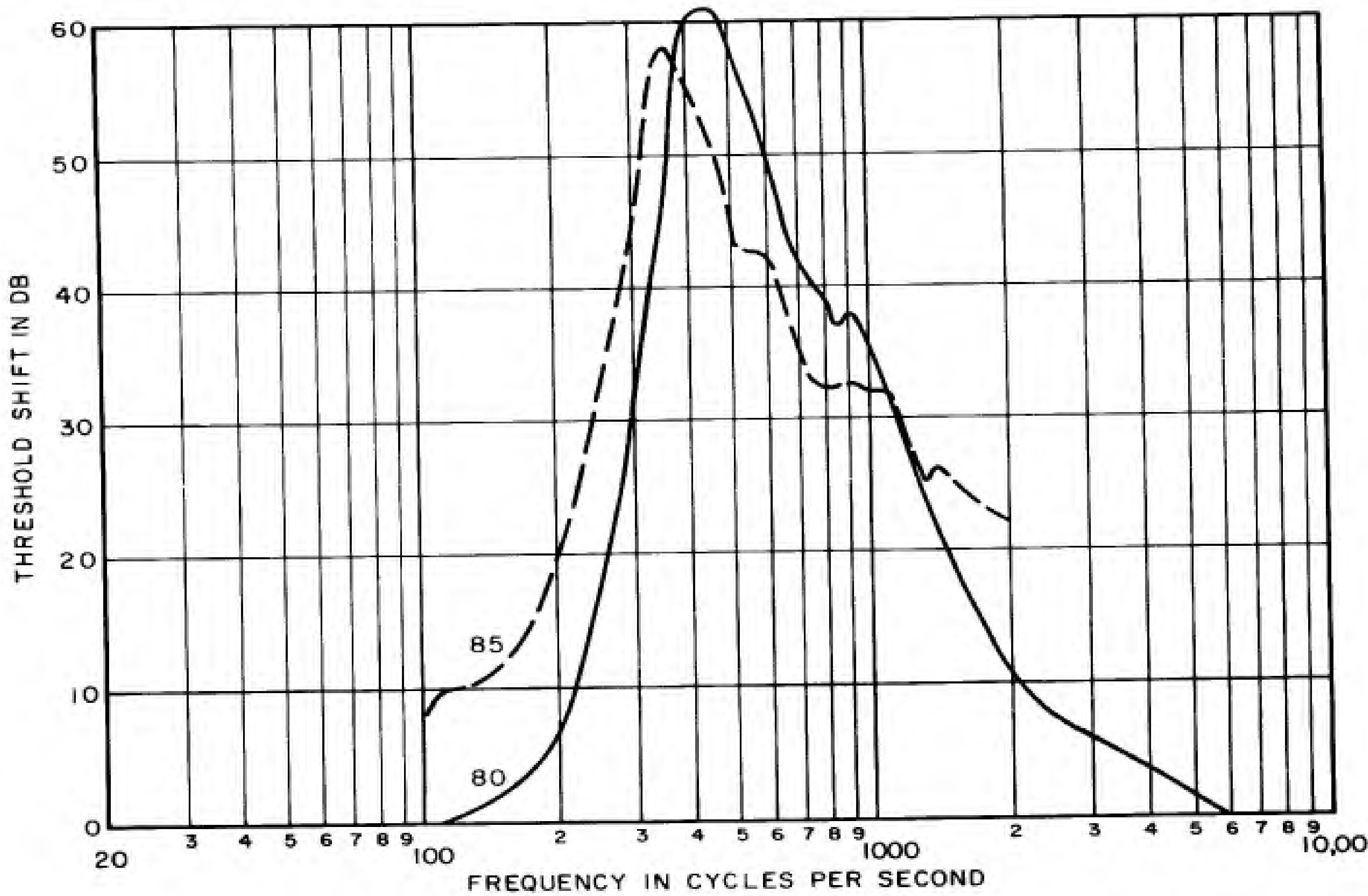

FIG. 37 MASKING DUE TO NARROW BAND NOISE. DASHED CURVES ARE FROM PRESENT STUDY USING A 350 TO 450 CPS BAND. THE SOLID CURVE IS FROM EGAN AND HAKE[10] (OF FIG. 15) AND REPRESENTS MASKING DUE TO A 90 CPS WIDE NOISE BAND CENTERED AT 400 CPS. PARAMETER IS THE SPL OF THE MASKING NOISE.

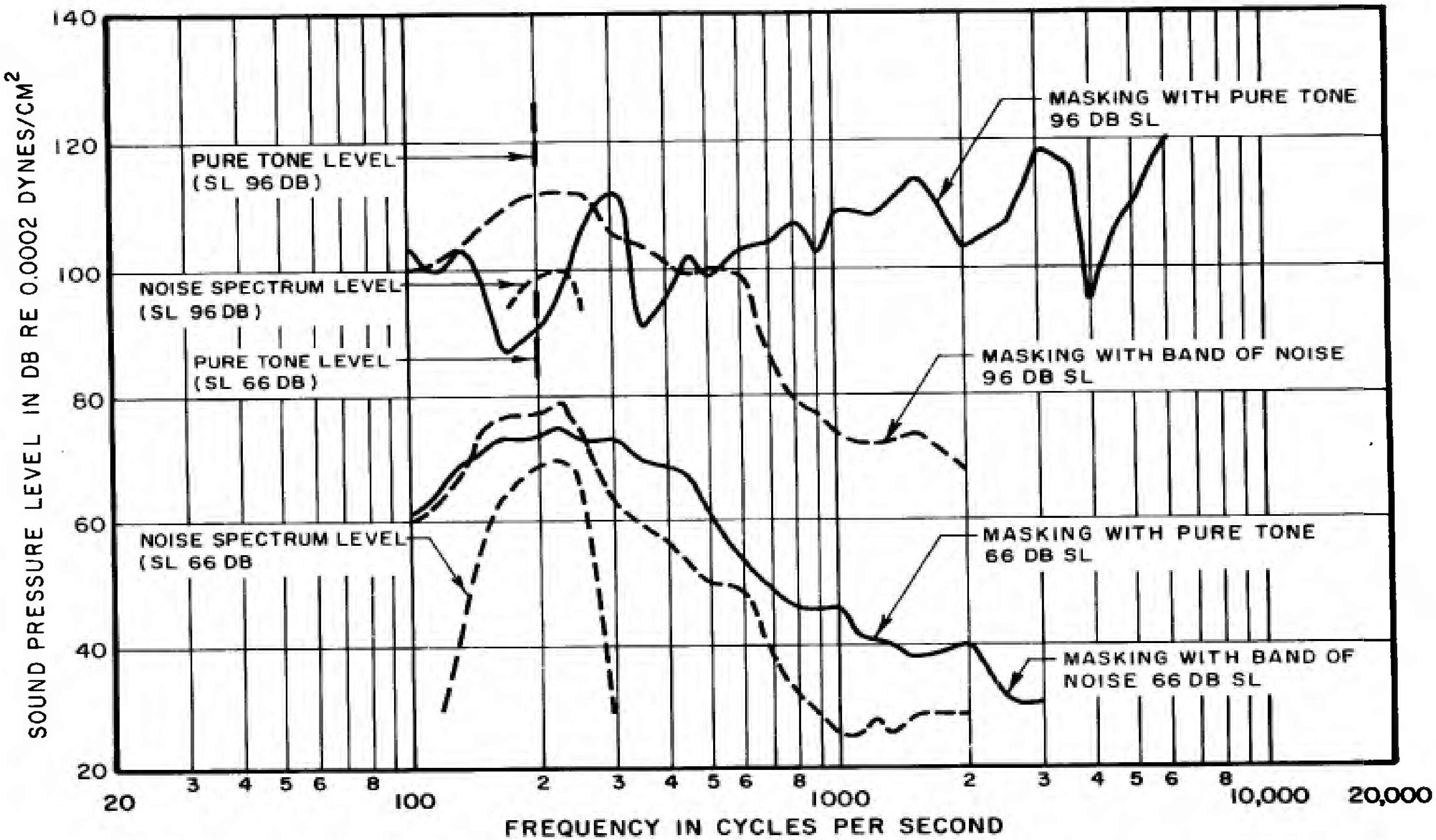

FIG. 38 MASKING DUE TO A 200 CPS MASKING TONE (SOLID CURVES, ESTIMATED FROM FIG. 6) AND A 150 TO 250 CPS MASKING NOISE (FIG. 27, 28). THE PARAMETER IS THE SENSATION LEVEL (LEVEL ABOVE THRESHOLD IN DB) OF THE TONE AND NOISE, DETERMINED EMPIRICALLY FOR THESE APPARATUS AND SUBJECTS.

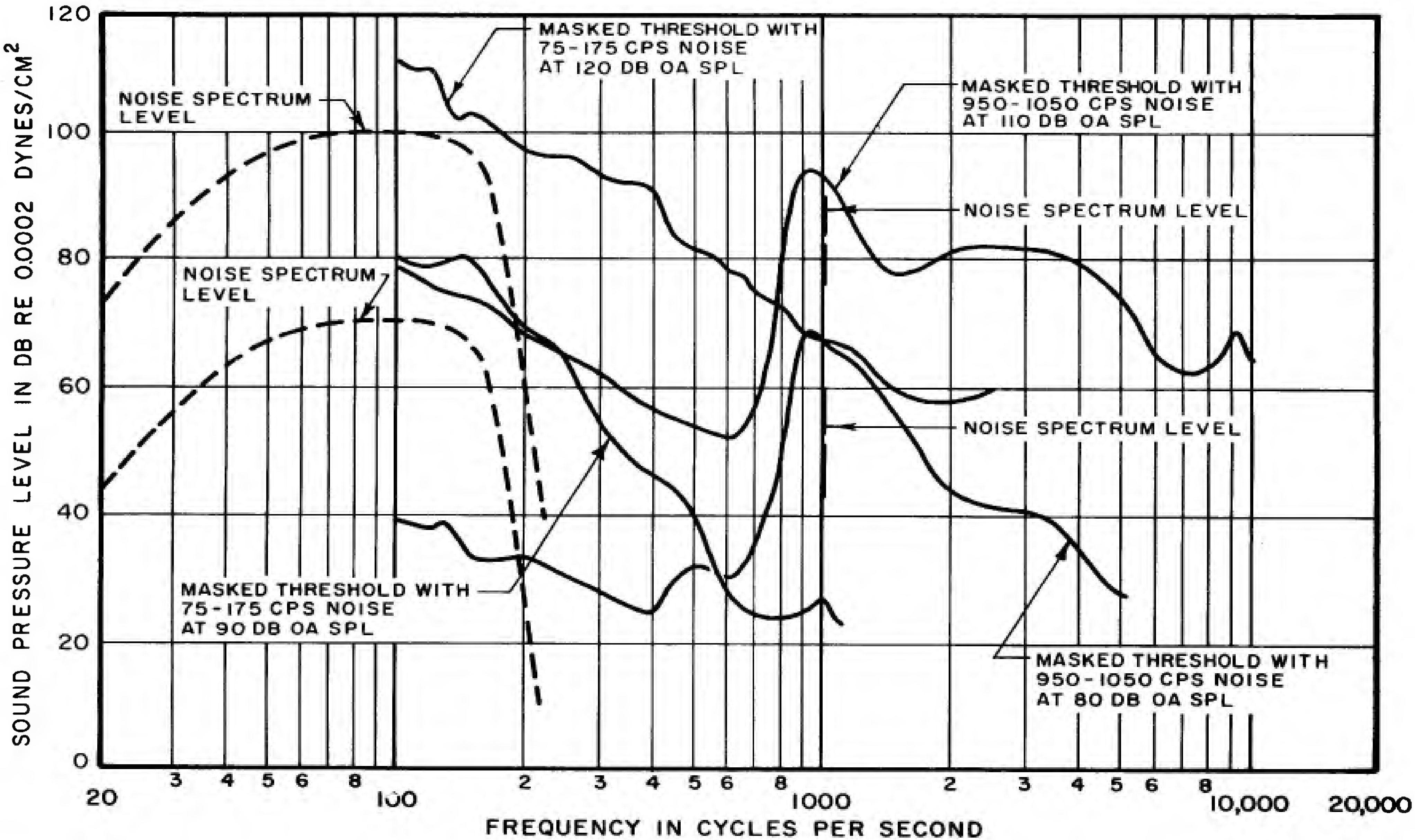

FIG. 39 MASKING DUE TO A 75 TO 175 CPS AND A 950 TO 1050 CPS BAND OF NOISE.

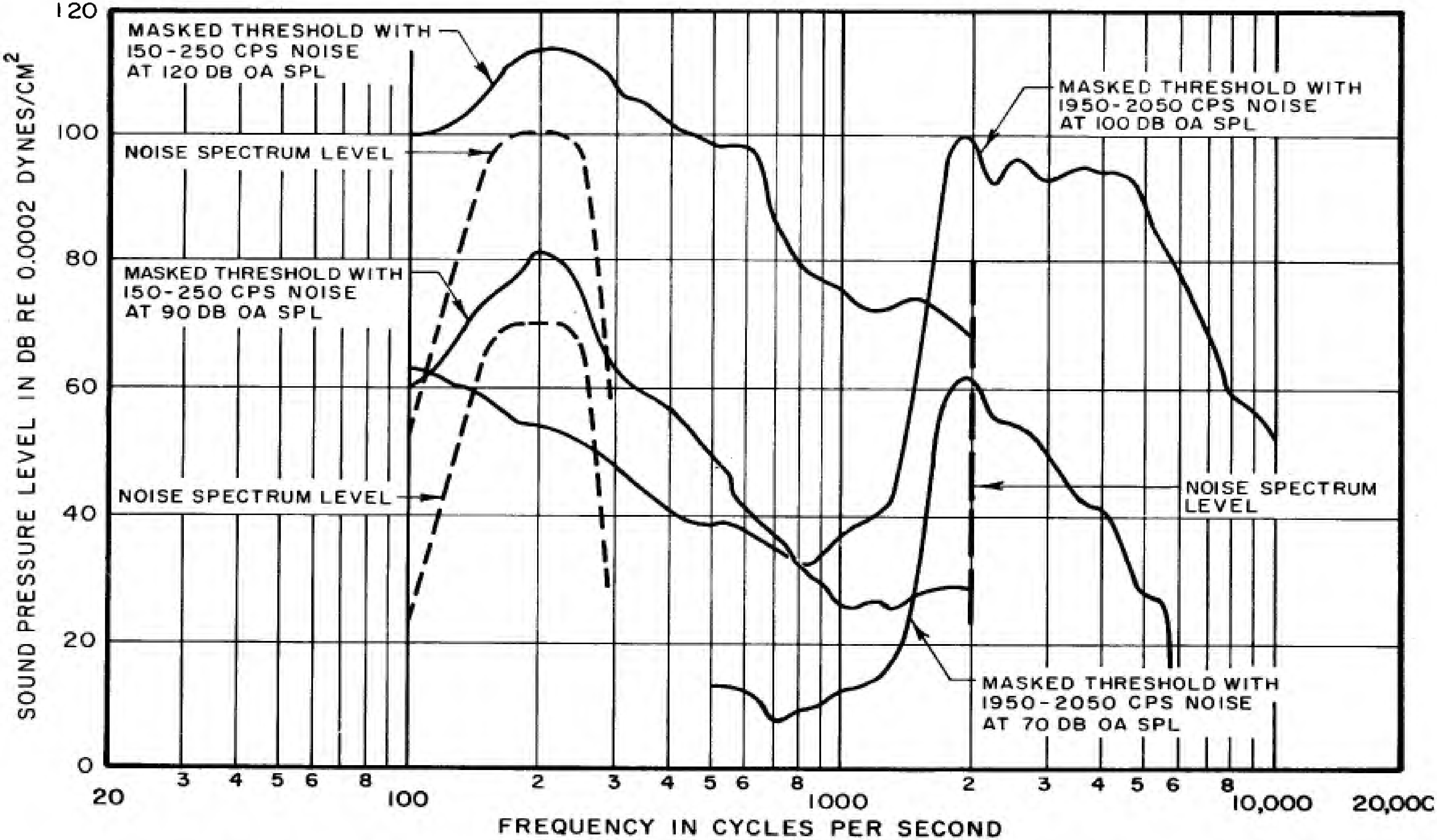

FIG. 40 MASKING DUE TO A 150 TO 250 CPS AND A 1950 TO 2050 CPS BAND OF NOISE.

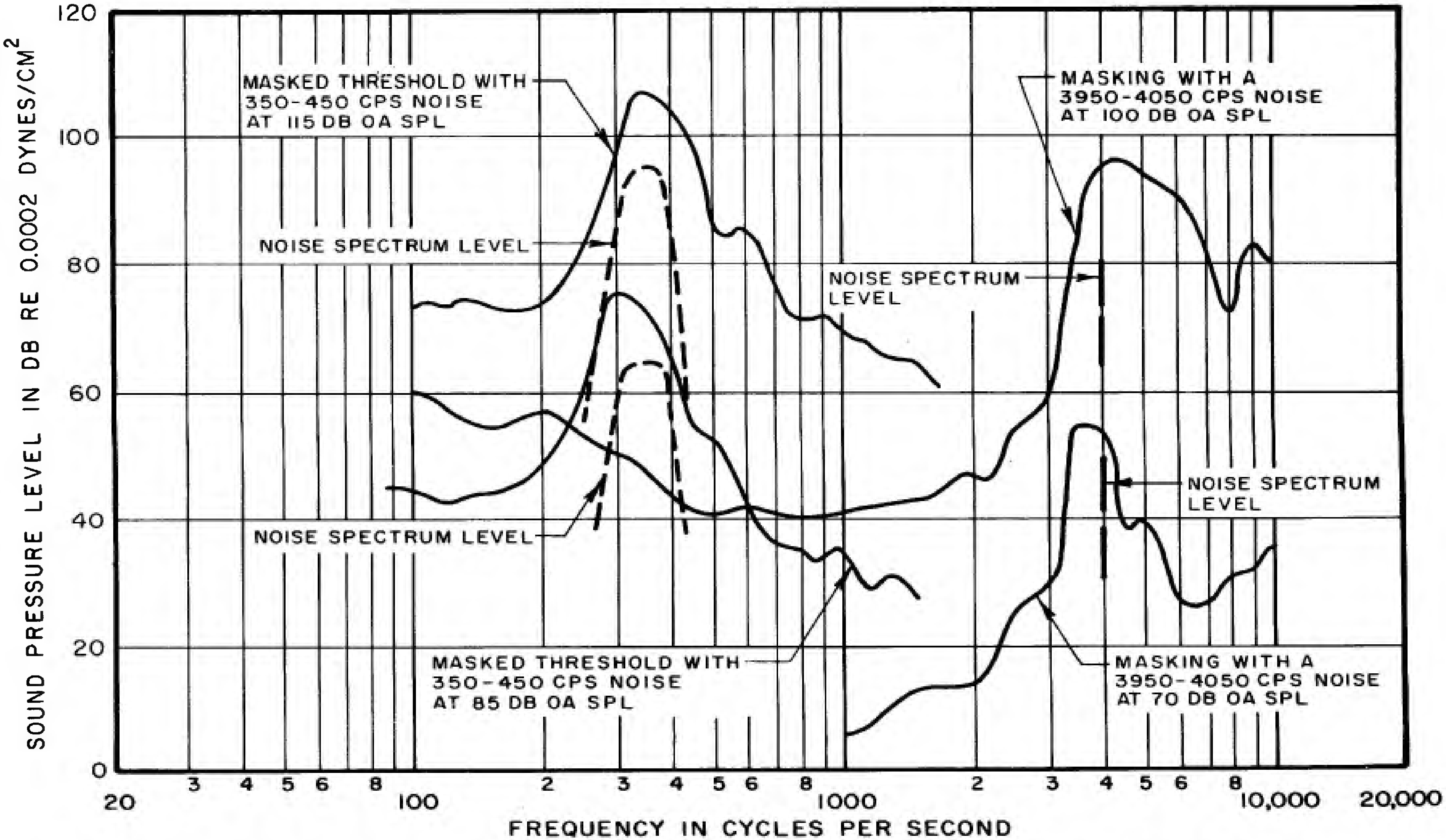

FIG. 41 MASKING DUE TO A 350 TO 450 CPS AND A 3950 TO 4050 CPS BAND OF NOISE.

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